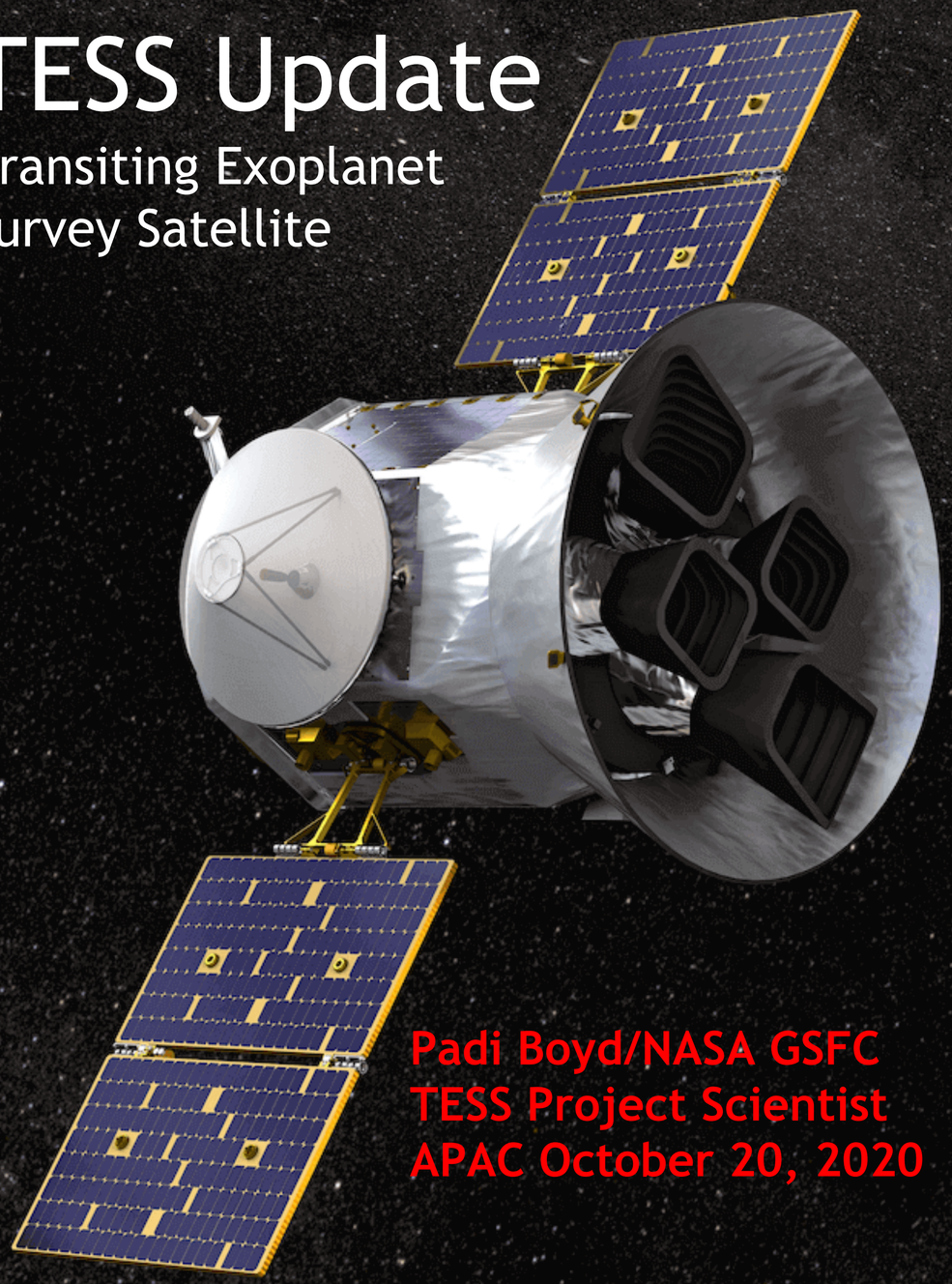
TESS Update

Transiting Exoplanet Survey Satellite



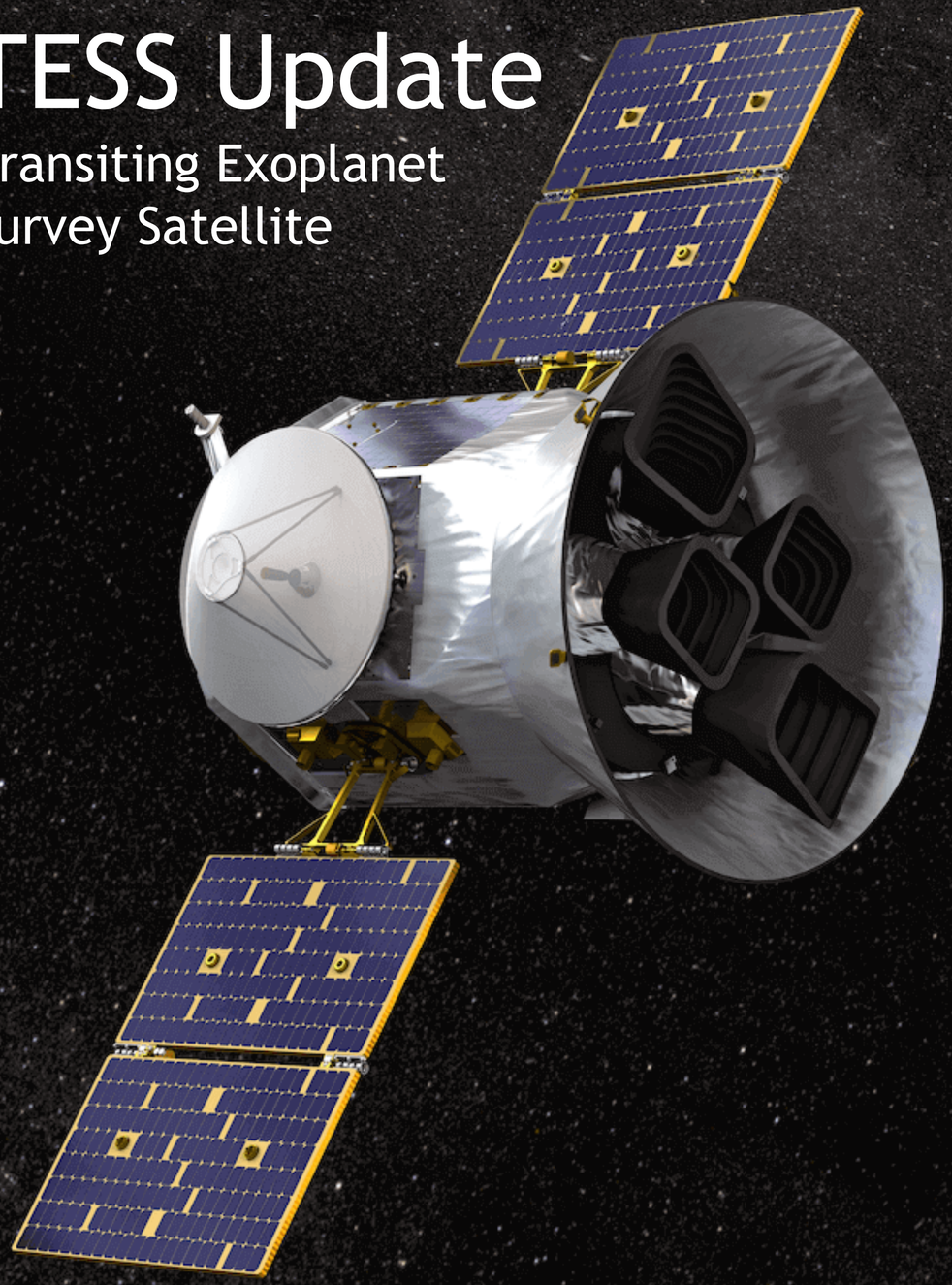
Padi Boyd/NASA GSFC
TESS Project Scientist
APAC October 20, 2020

TESS is a NASA Astrophysics Explorer mission led and operated by MIT in Cambridge, Massachusetts, and managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland. Dr. George Ricker of MIT's Kavli Institute for Astrophysics and Space Research serves as principal investigator for the mission. Additional partners include Northrop Grumman, based in Falls Church, Virginia; NASA's Ames Research Center in California's Silicon Valley; the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts; MIT's Lincoln Laboratory in Lexington, Massachusetts; and the Space Telescope Science Institute in Baltimore. More than a dozen universities, research institutes and observatories worldwide are participants in the mission.

Last update: Oct 14, 2020

TESS Update

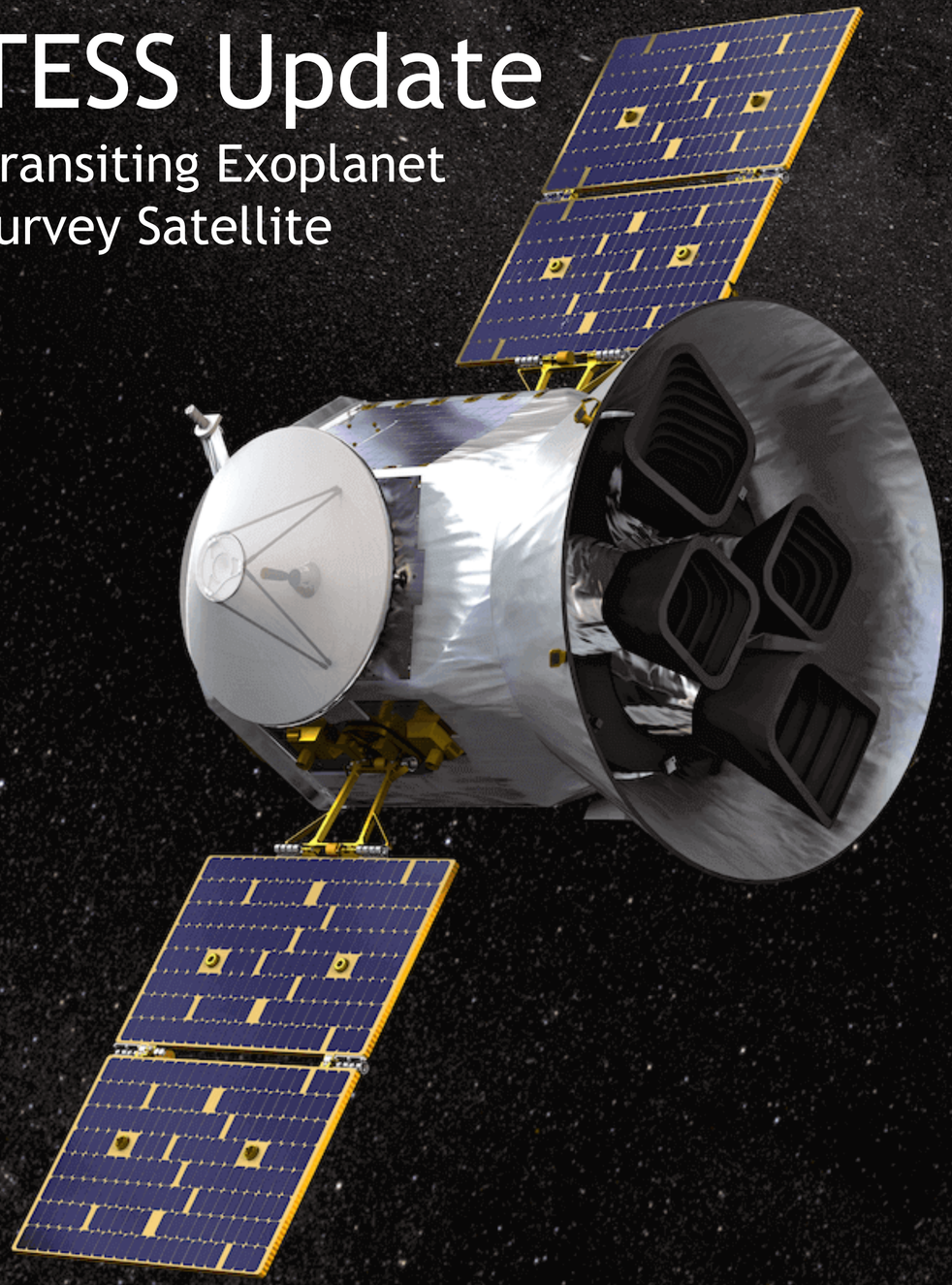
Transiting Exoplanet
Survey Satellite



Last update: Oct 14, 2020

TESS Update

Transiting Exoplanet
Survey Satellite



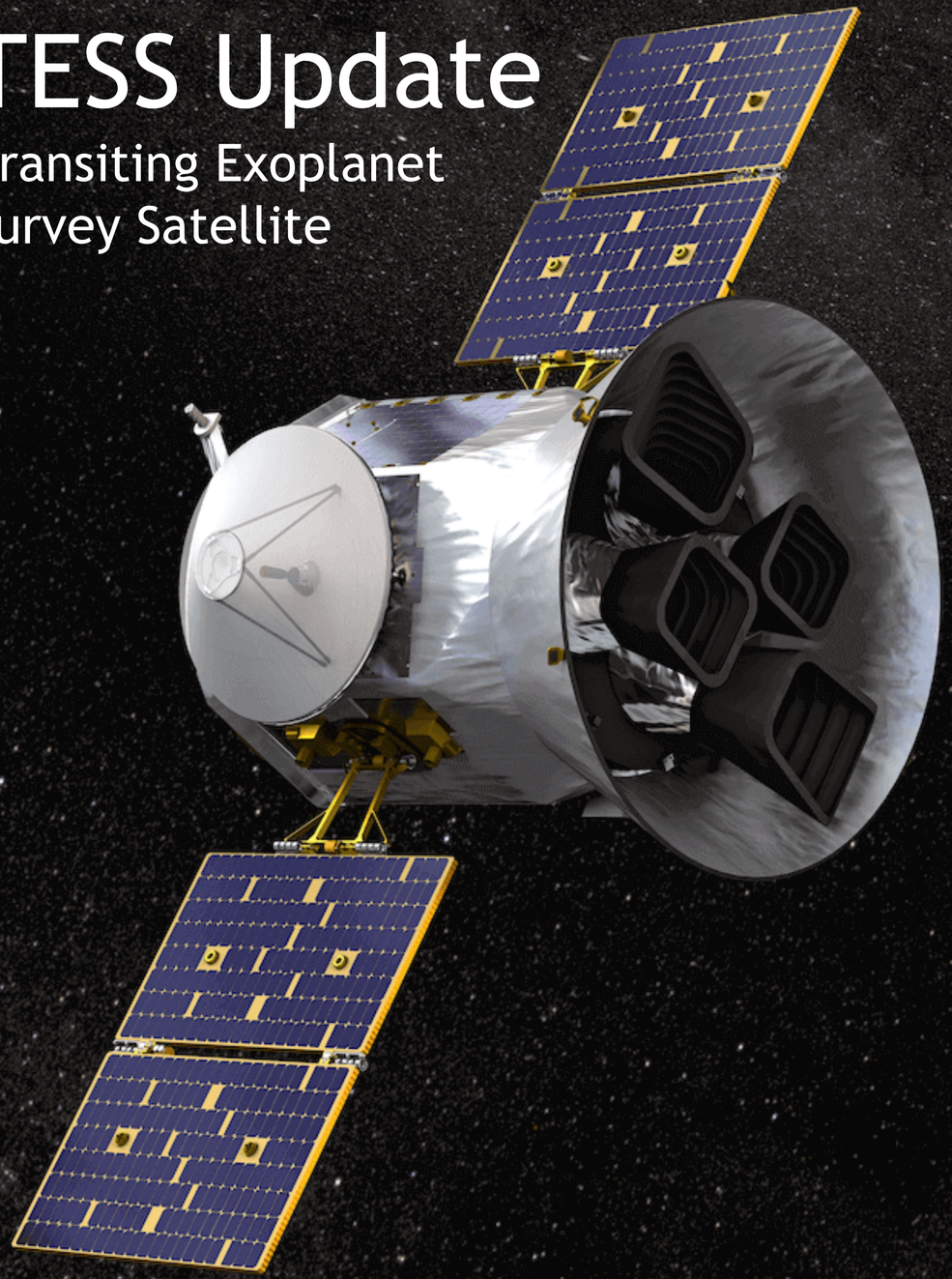
Extended Mission Began
July 5, 2020

Observation Sector 30/31
Orbits 67 & 68
Sept 22 - Oct 21

Last update: Oct 14, 2020

TESS Update

Transiting Exoplanet
Survey Satellite



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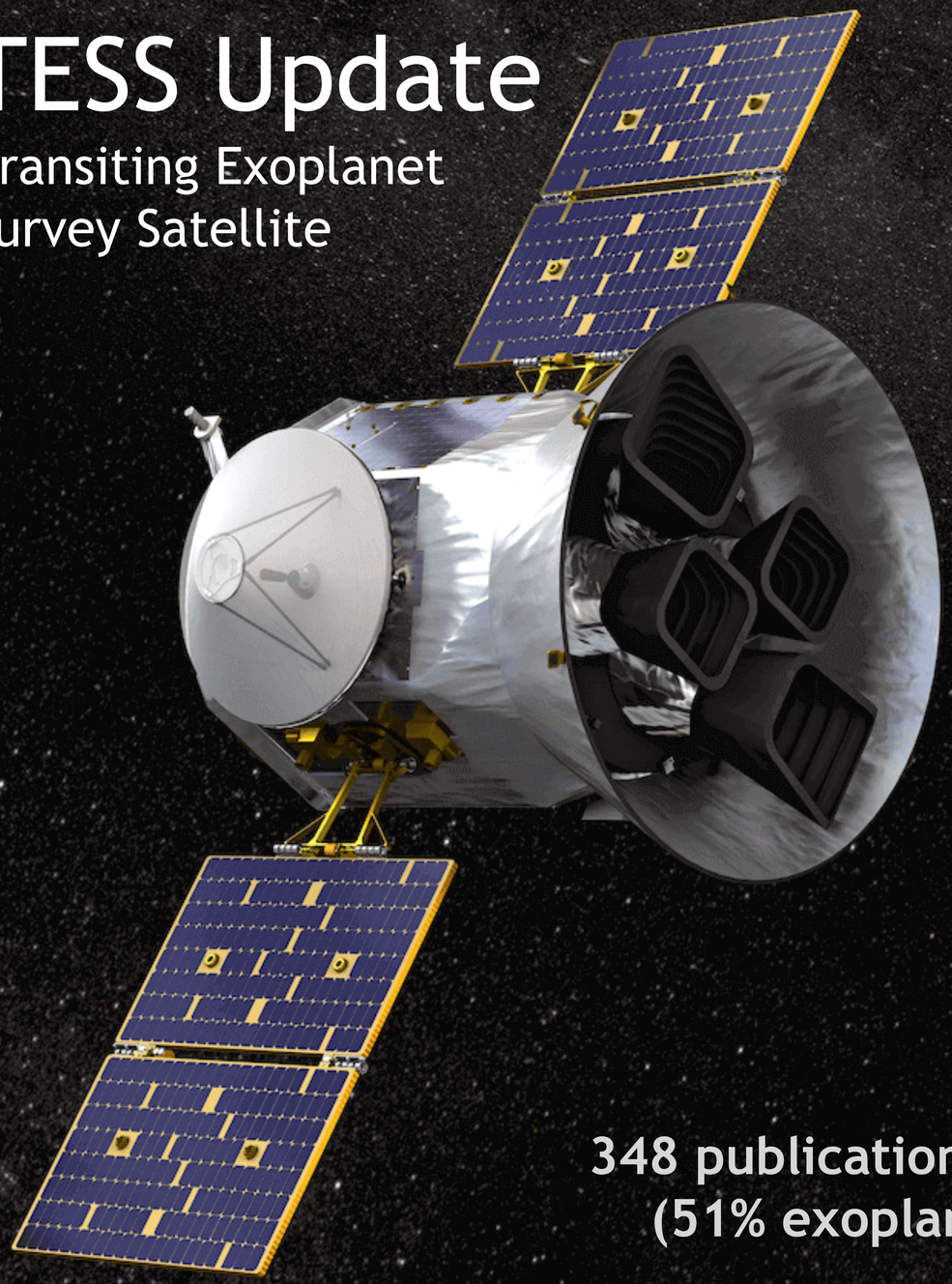
79 confirmed planets
2330 planet candidates

Last update: Oct 14, 2020

TESS Update

Transiting Exoplanet
Survey Satellite



Extended Mission Began
July 5, 2020

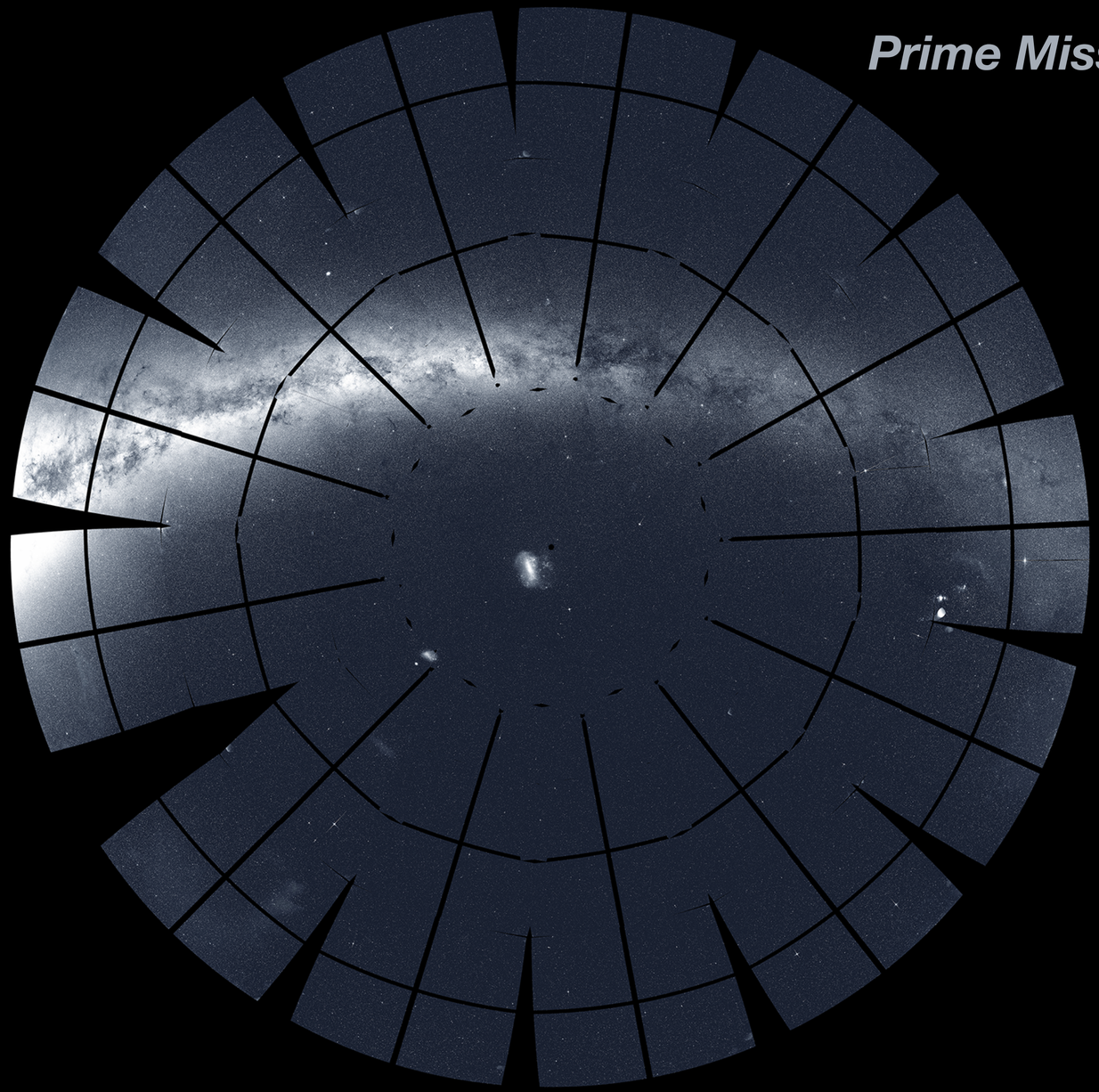
Observation Sector 30/31
Orbits 67 & 68
Sept 22 - Oct 21

79 confirmed planets
2330 planet candidates

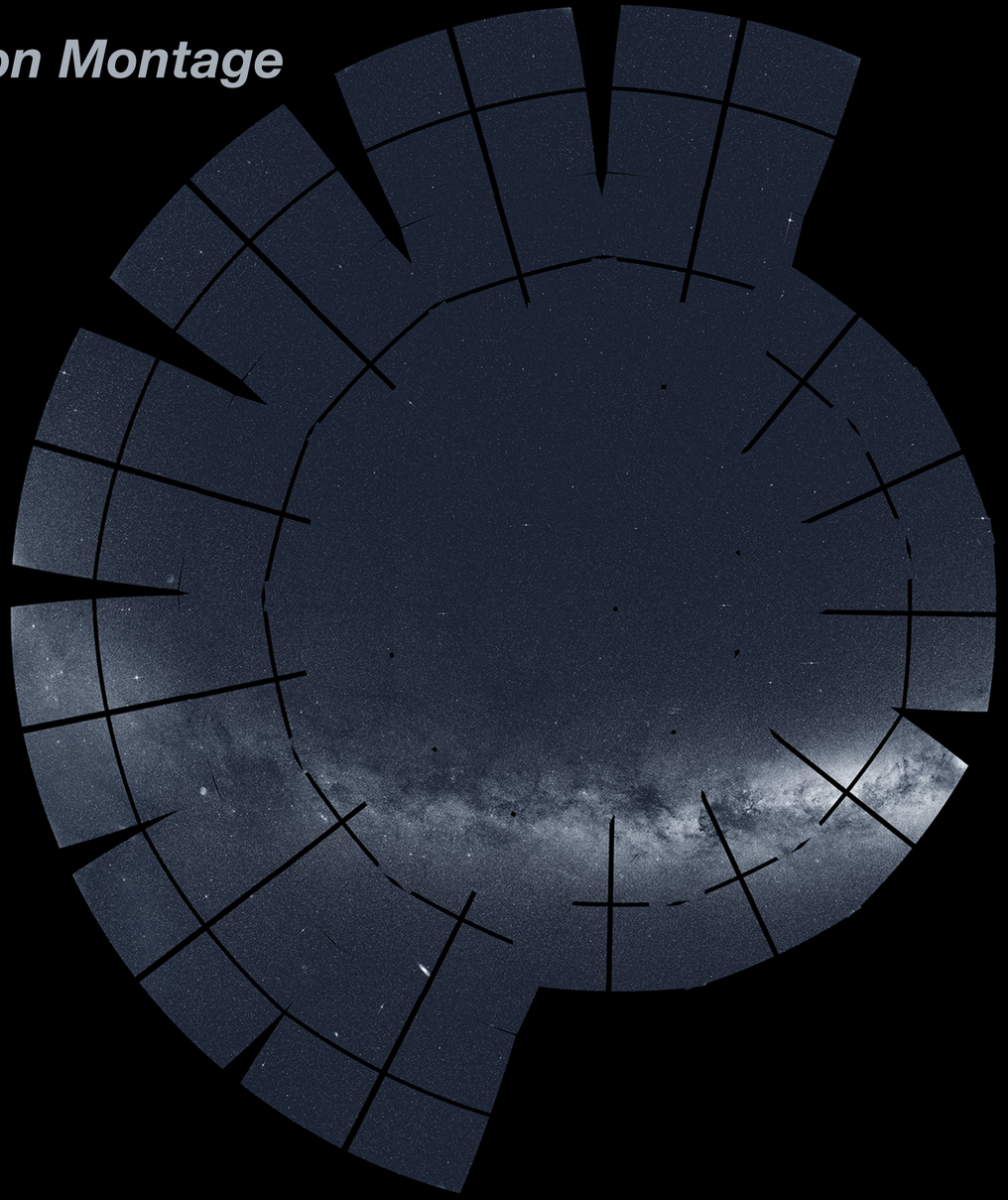
348 publications submitted, 285 peer-reviewed
(51% exoplanets, 49% astrophysics)

Last update: Oct 14, 2020

Prime Mission Montage

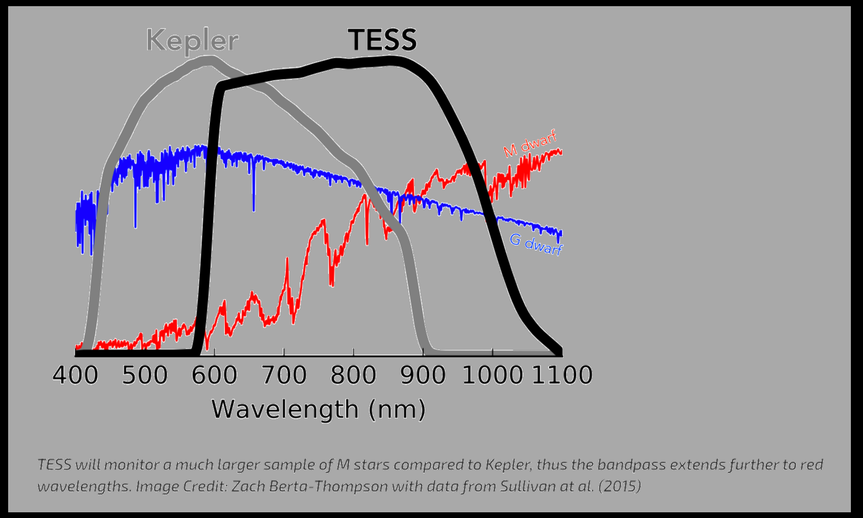


South Ecliptic Pole View, Year 1 (Sectors 1-13)

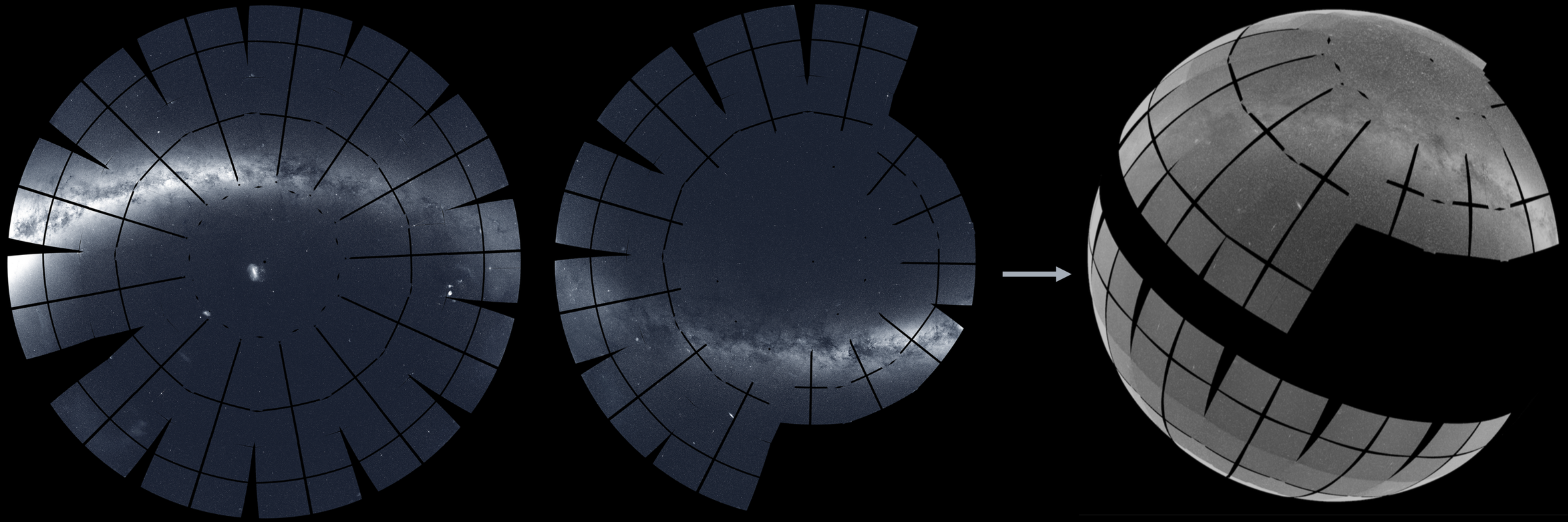


North Ecliptic Pole View, Year 1 (Sectors 14-26)

Prime Mission Montage



TESS will monitor a much larger sample of M stars compared to Kepler, thus the bandpass extends further to red wavelengths. Image Credit: Zach Berta-Thompson with data from Sullivan at al. (2015)



R. Vanderspek (MIT)

COVID-19 related shutdowns hit right in the middle of Sector 22, Since then…

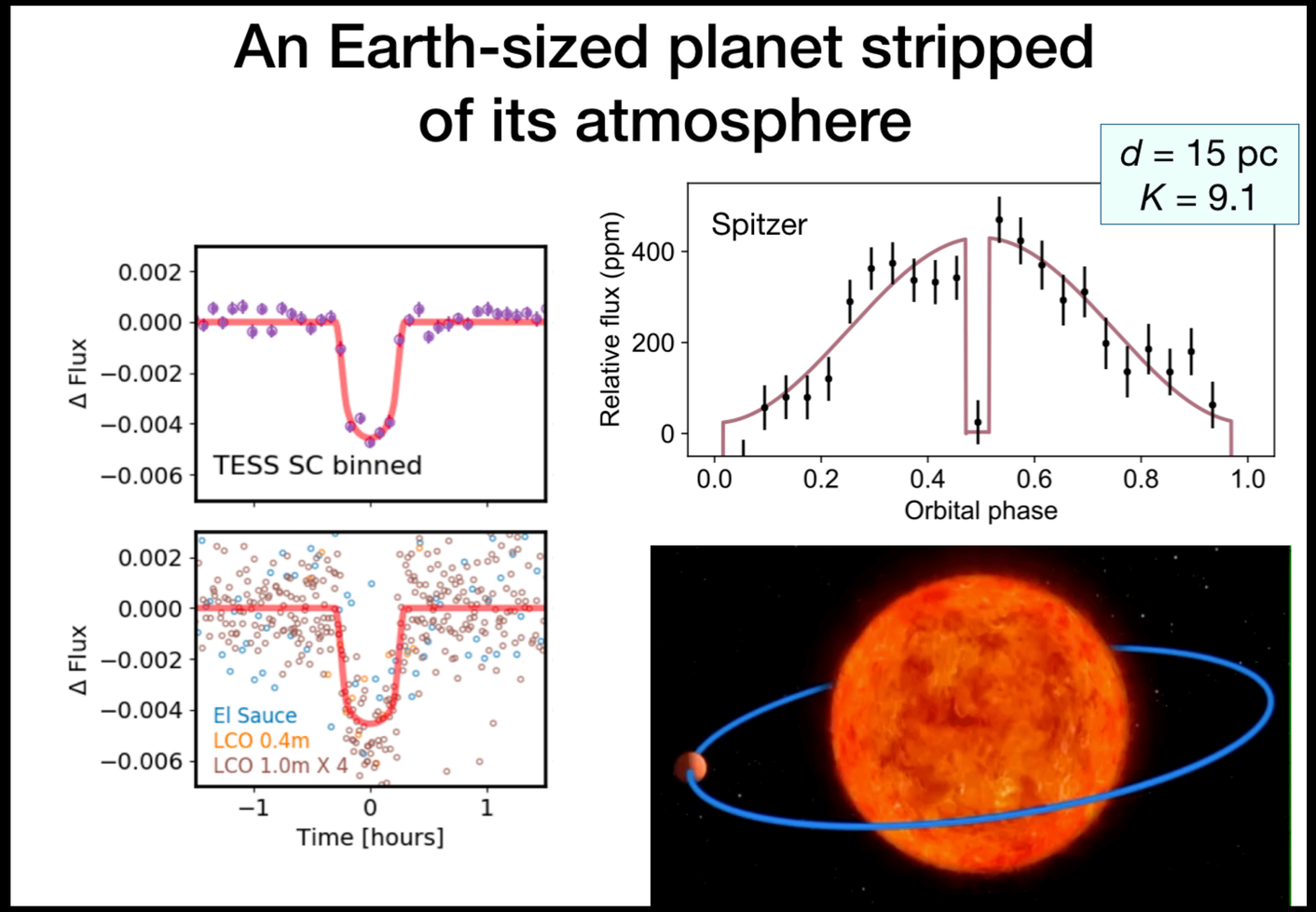
- 9+ Sectors have completed successfully, during mostly-mandatory telework
- Operations teams (POC, SPOC, TSO, MAST) and science/mission support teams (SSMO, NGSS, TFOP, NExScI, GI Office) still hunkered down and working smoothly
- Zoom, WebEx, MicroSoft Teams working well for communication
- Team has done a remarkable job responding flexibly to challenges such as minimal on-site support staff, ground-based observatory shutdowns and changing from in-person activities to the virtual environment

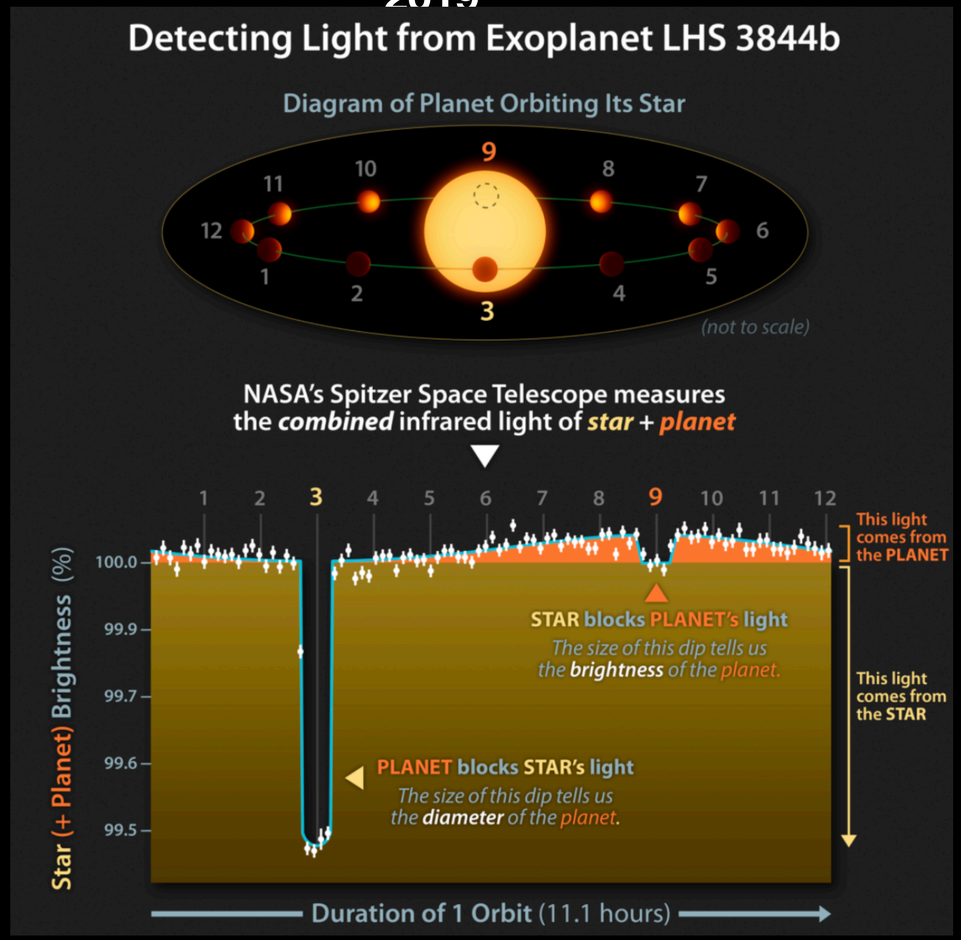
TESS Launch Anniversary Zoom Party April 18, 2020

TESS Planet Discovery: LHS 3844b

TESS Discovery of an Ultra-short-period Planet around the Nearby M Dwarf LHS 3844, *ApJL*, Vanderspek et al., 2019

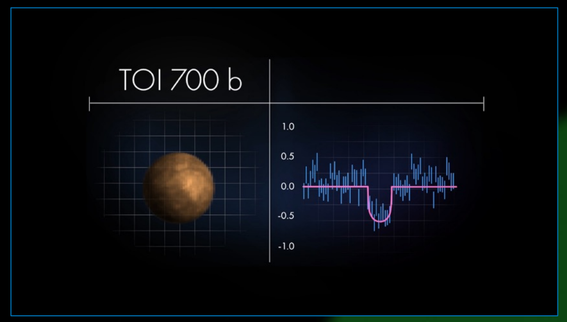
Absence of a Thick Atmosphere on the Terrestrial Exoplanet LHS 3844b, *Nature*, Kreidberg *et al.*, 2019

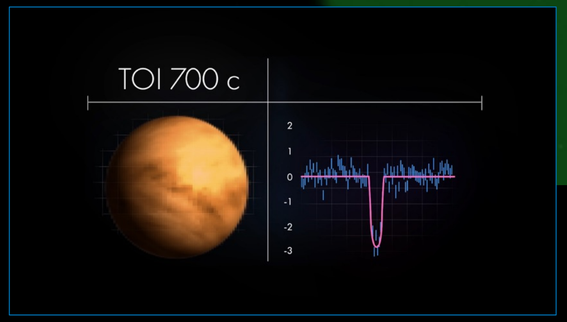


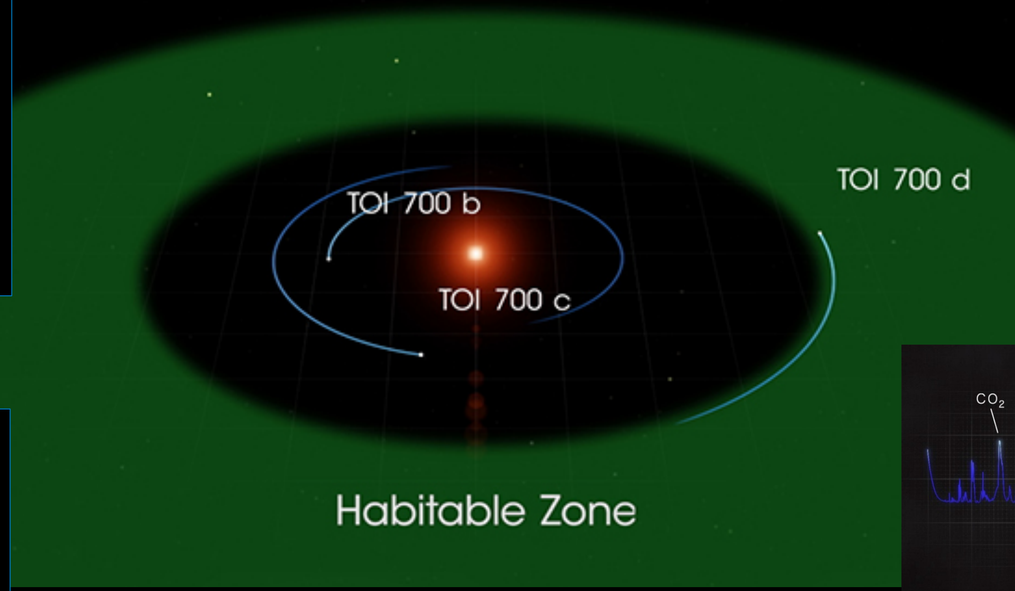


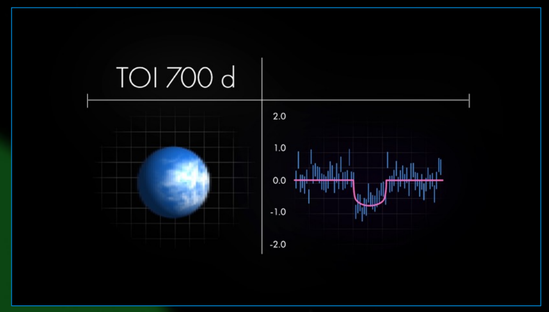
"LHS 3844b, a 1.3-Earth-radii terrestrial world in an 11-hour orbit around the small nearby star LHS 3844, very likely has little to no atmosphere and could be covered in the same cooled volcanic material that comprises the dark lunar regions known as mare, according to new research."

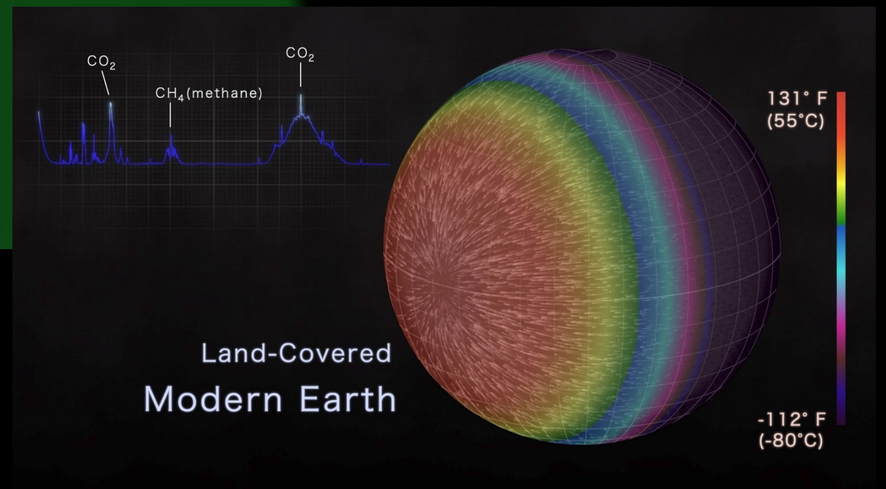
TESS Planet Discovery: TOI 700









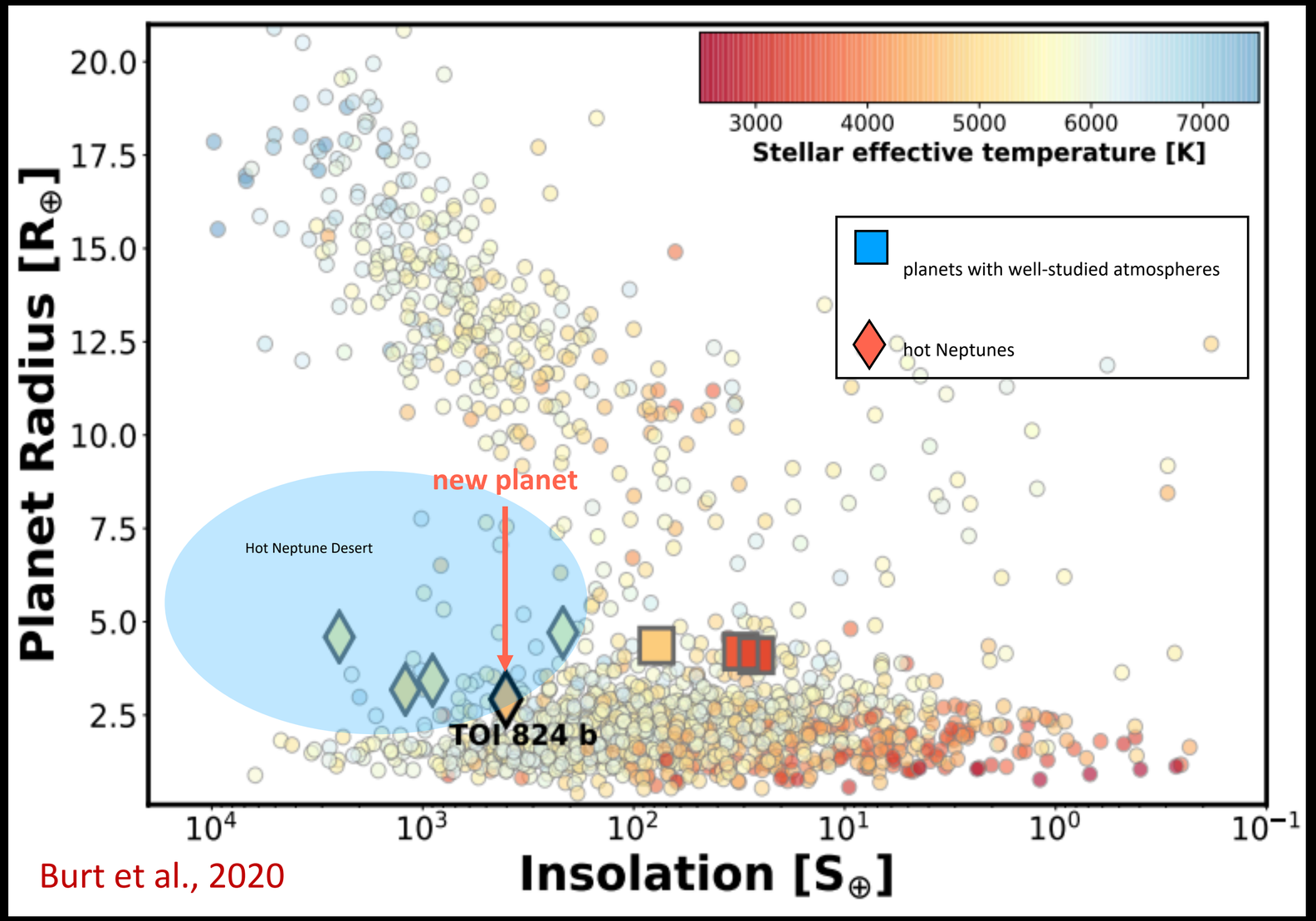


TOI 700, a red dwarf star 101.4 light-years away in the Dorado constellation. The exoplanet TOI-700d is the first Earth-sized exoplanet in the habitable zone discovered by the Transiting Exoplanet Survey Satellite. (2020)

Gilbert et al, Rodriguez et al., Suissa et al., 2020

"We find that TOI-700 d is a strong candidate for a habitable world and can potentially maintain temperate surface conditions under a wide variety of atmospheric compositions. Unfortunately, the spectral feature depths from the resulting transmission spectra and the peak flux and variations from our synthesized phase curves for TOI-700 d do not exceed 10 ppm.
This will likely prohibit the James Webb Space Telescope (JWST) from characterizing its atmosphere; …"

A New Planet on the Lower Edge of the Hot Neptune Desert: TOI-824 b



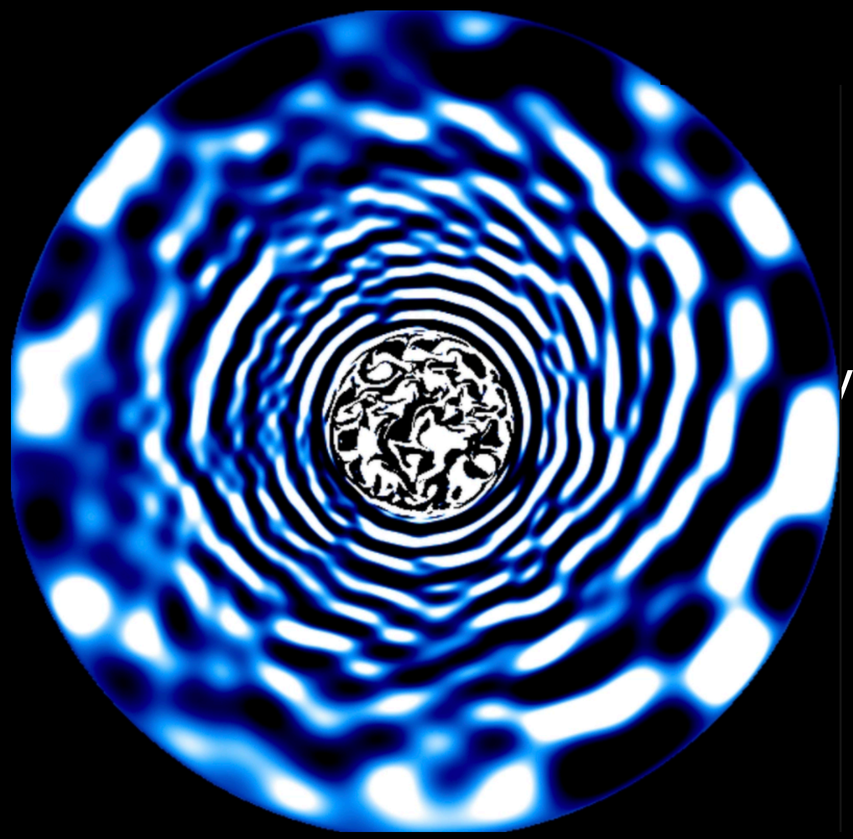
Burt et al., 2020

The “hot Neptune desert” refers to the dearth of planets the size and mass of Neptune on periods shorter than 4 days

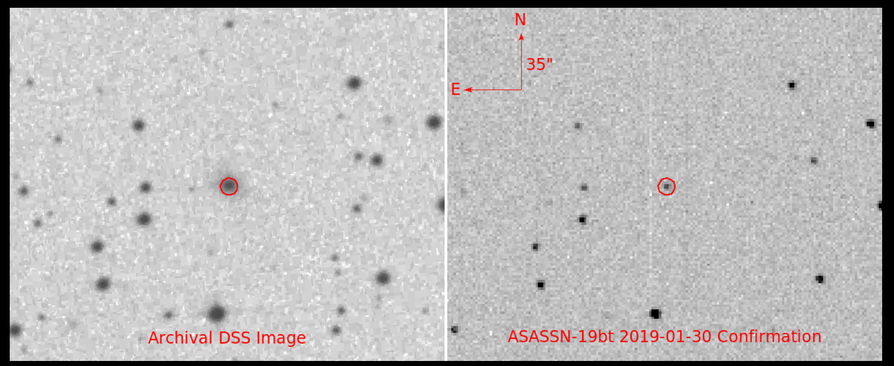
TOI-824 b has a precise mass and likely a cloud-free atmosphere, making it a promising target for the detection of atmospheric escape

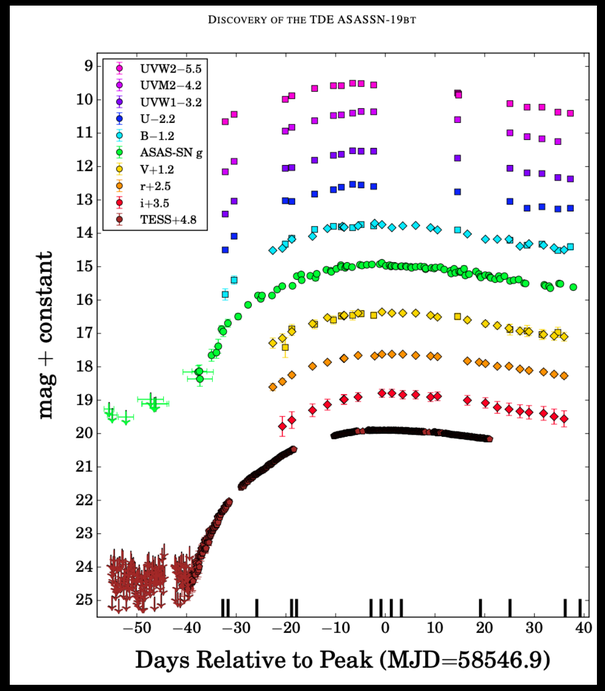
“The detectability of TOI-824 b's atmosphere from both ground and space is promising and could lead to the detailed characterization of the most irradiated, small planet at the edge of the hot Neptune desert that has retained its atmosphere to date.” Burt et al., 2020, AJ 160:153

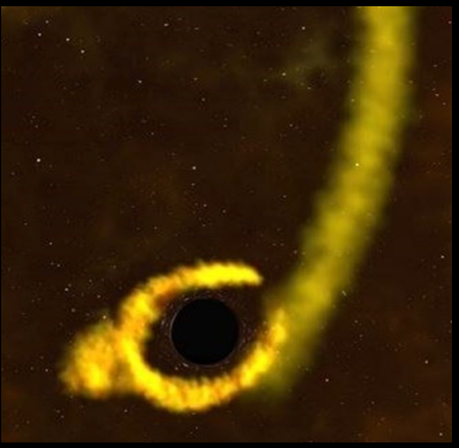
TESS: more than exoplanets!

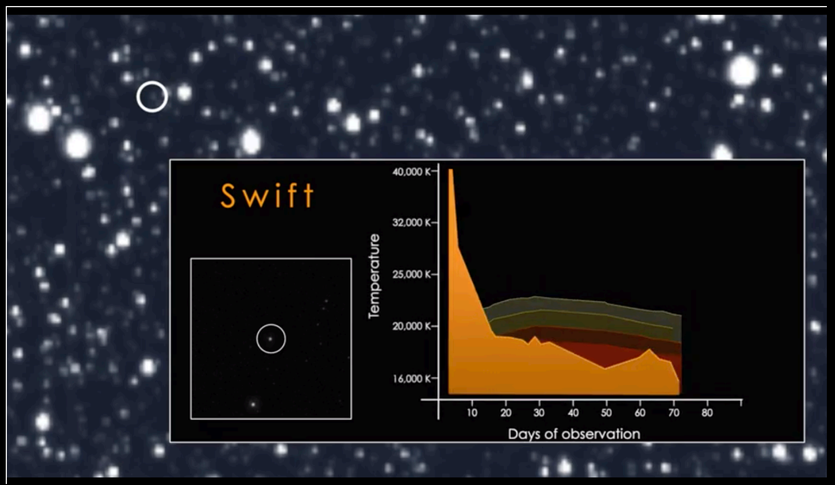


Low-frequency gravity waves in blue supergiants revealed by high-precision space photometry, *Nature Astronomy,* Bowman et al., 2019



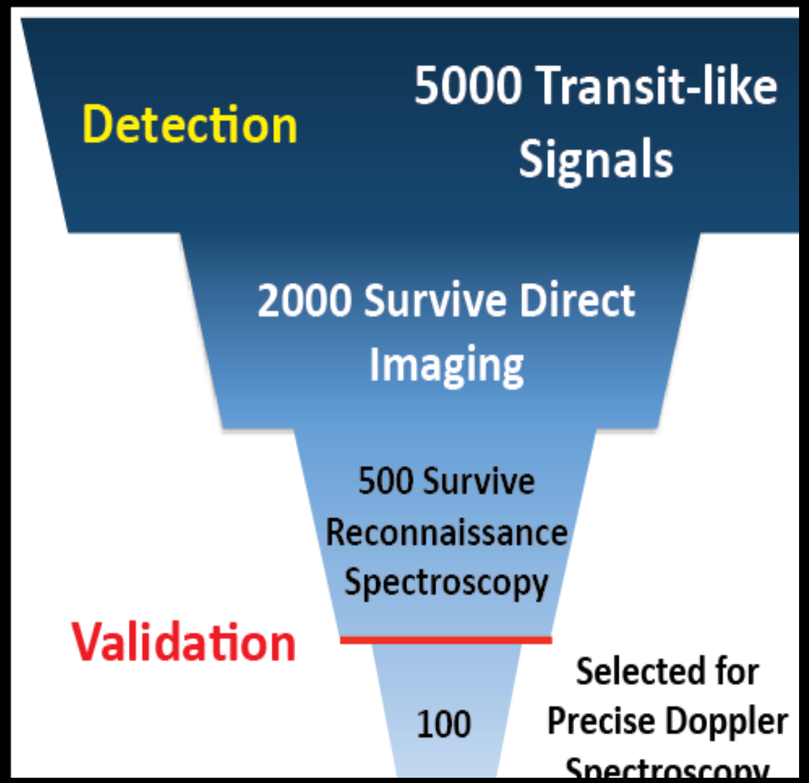


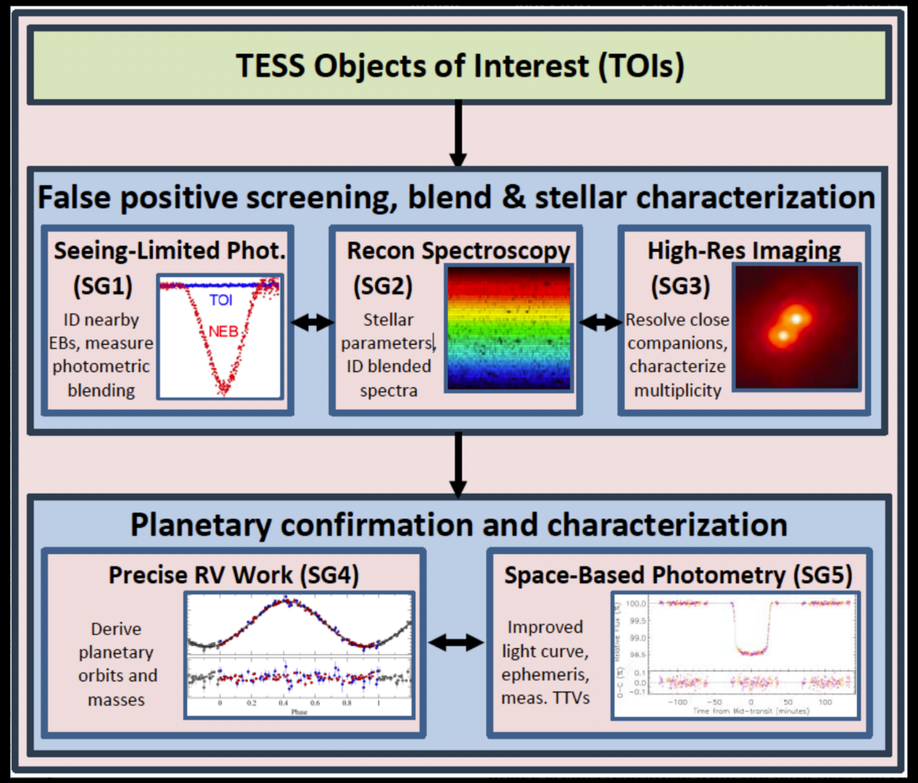


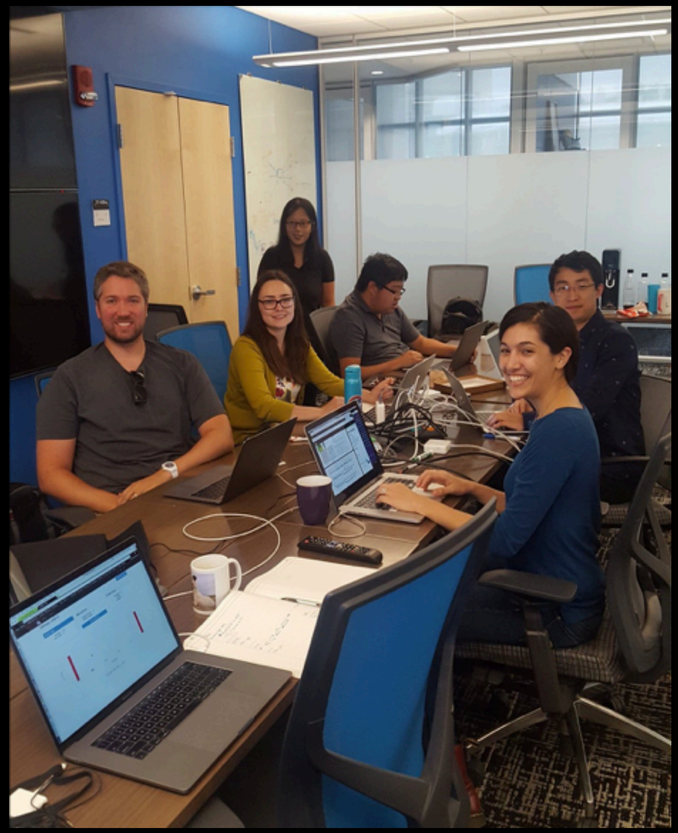


Discovery and Early Evolution of ASASSN-19bt, the First TDE Detected by TESS, *ApJ*, Holoien et al ., 2019

From detection to validation- people power





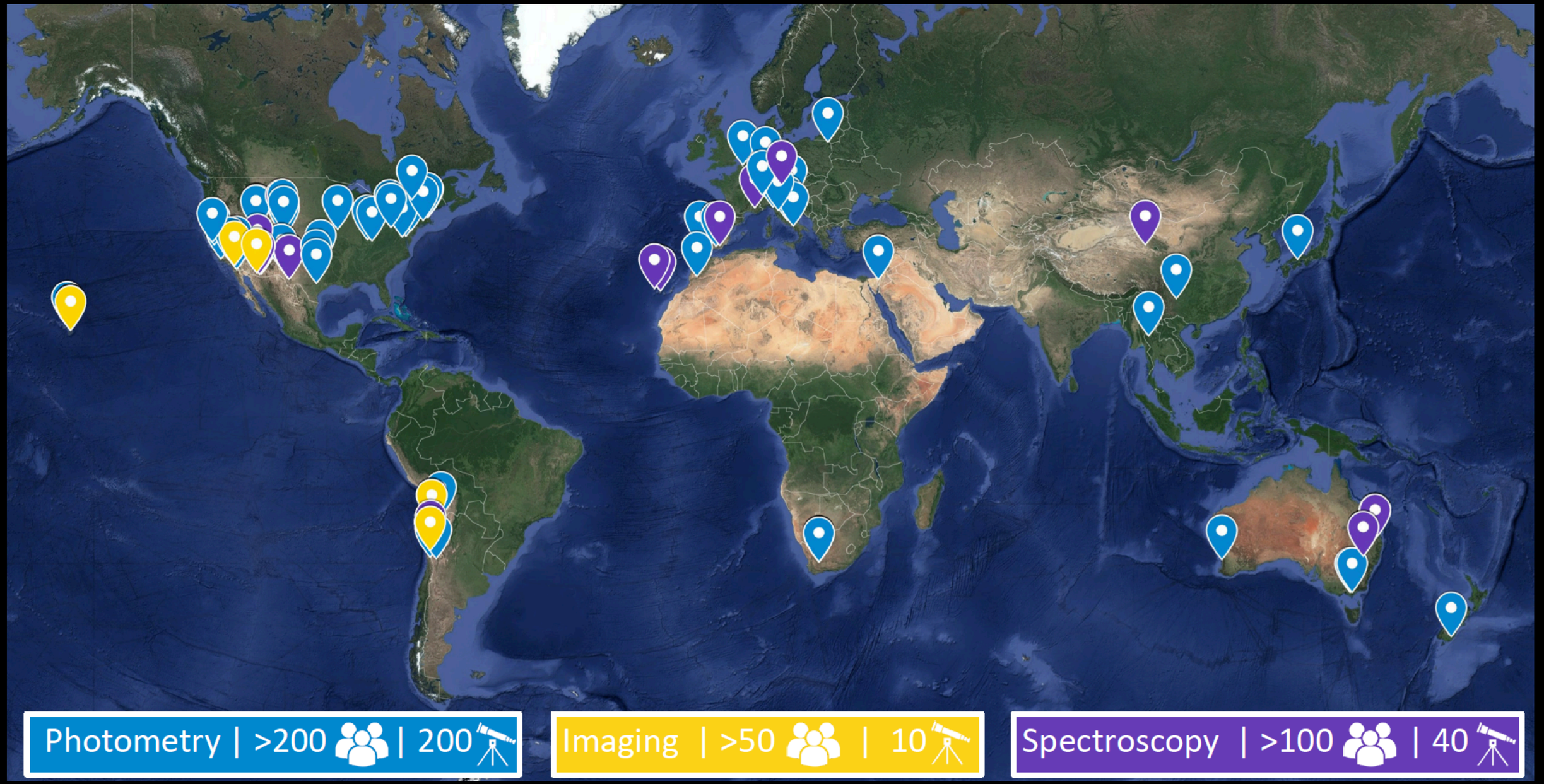


Immediately after each sector's data is processed:

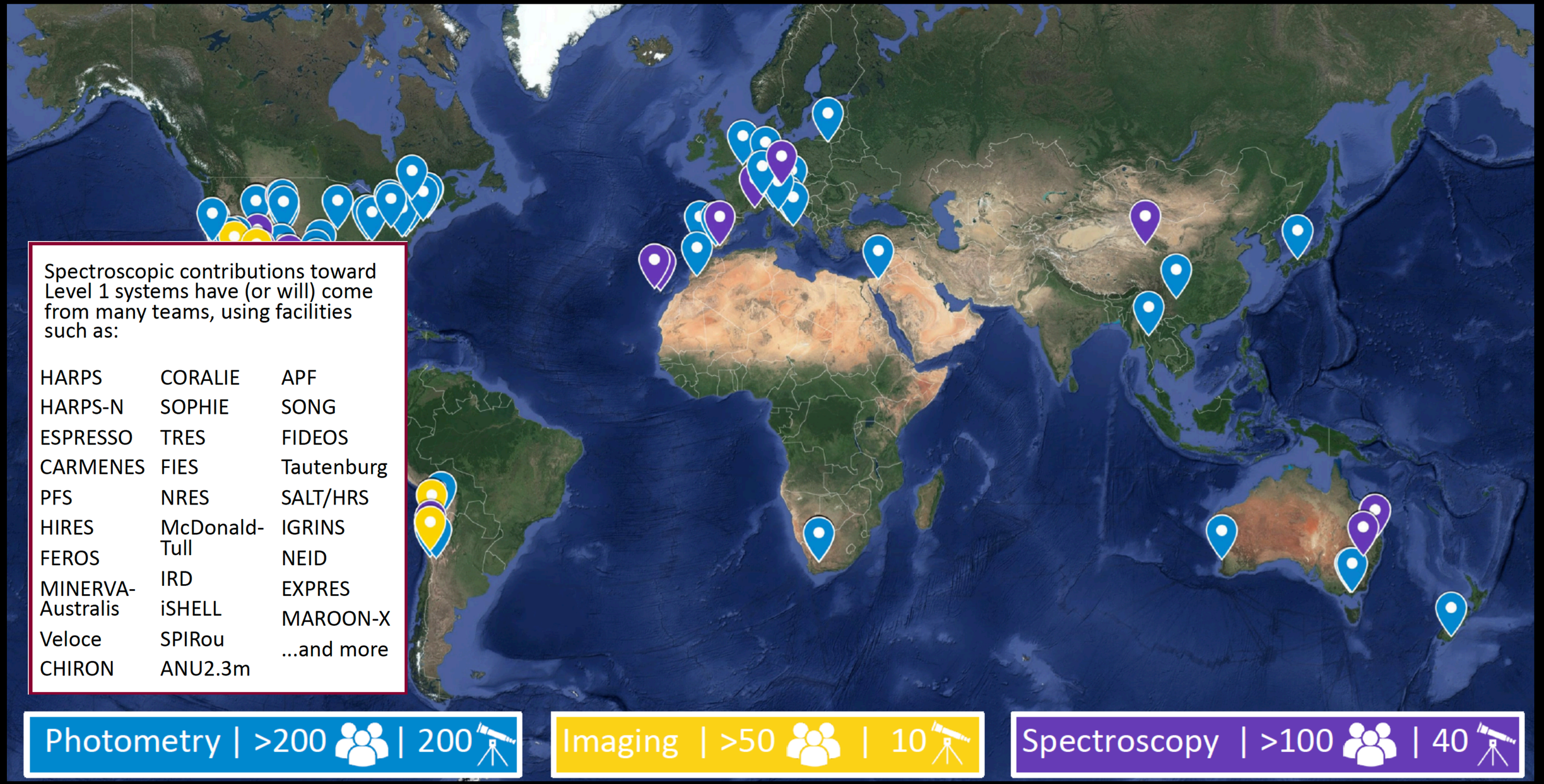
TOI Steering Committee turns "threshold crossing events" into TESS Objects of Interest (TOIs)

Funded TESS Follow-up Observing Program (TFOP) takes TOIs, prioritizes them according to 5 separate subgroups, organizes observations

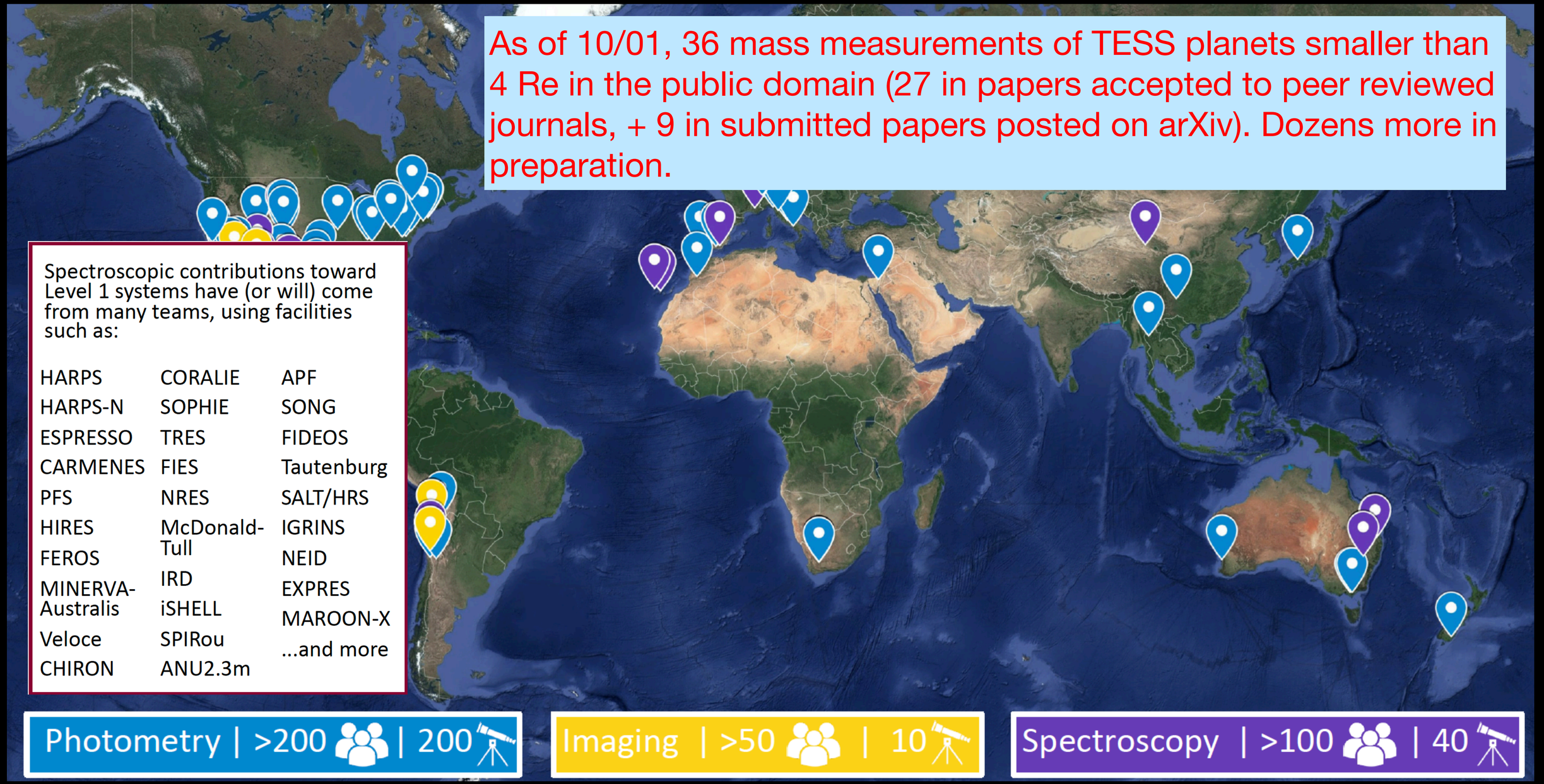
TESS Follow-Up Observing Program (TFOP) – graphic credit Sam Quinn (SAO)



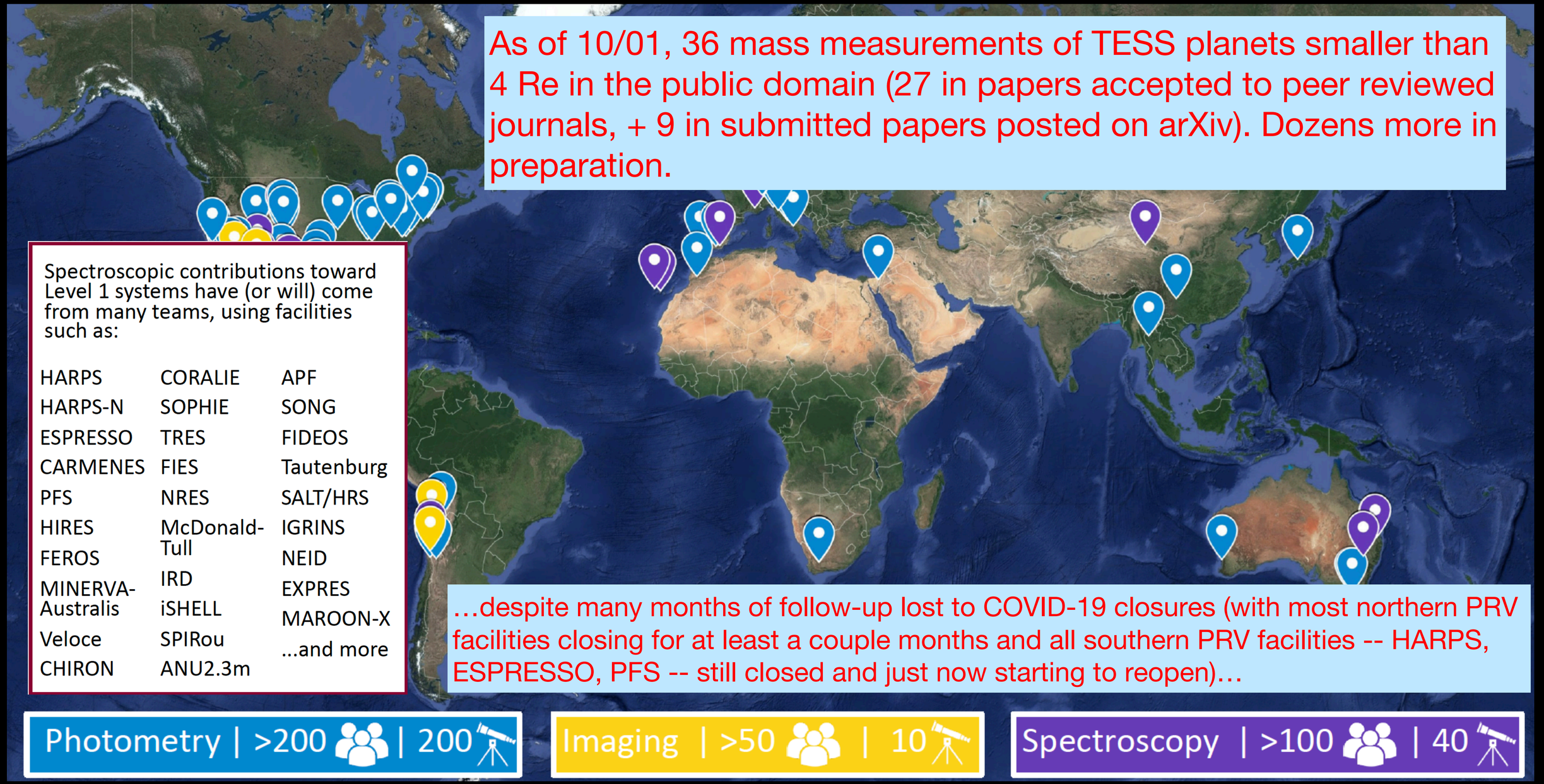
TESS Follow-Up Observing Program (TFOP) – graphic credit Sam Quinn (SAO)



TESS Follow-Up Observing Program (TFOP) – graphic credit Sam Quinn (SAO)



TESS Follow-Up Observing Program (TFOP) – graphic credit Sam Quinn (SAO)



As of 10/01, 36 mass measurements of TESS planets smaller than 4 Re in the public domain (27 in papers accepted to peer reviewed journals, + 9 in submitted papers posted on arXiv). Dozens more in preparation.

Spectroscopic contributions toward Level 1 systems have (or will) come from many teams, using facilities such as:

HARPS	CORALIE	APF
HARPS-N	SOPHIE	SONG
ESPRESSO	TRES	FIDEOS
CARMENES	FIES	Tautenburg
PFS	NRES	SALT/HRS
HIRES	McDonald-Tull	IGRINS
FEROS	IRD	NEID
MINERVA-Australis	iSHELL	EXPRES
Veloce	SPIRou	MAROON-X
CHIRON	ANU2.3m	...and more

…despite many months of follow-up lost to COVID-19 closures (with most northern PRV facilities closing for at least a couple months and all southern PRV facilities -- HARPS, ESPRESSO, PFS -- still closed and just now starting to reopen)…

Photometry | >200 | 200

Imaging | >50 | 10

Spectroscopy | >100 | 40

Welcome to ExoFOP-TESS

The Exoplanet Follow-up Observing Program for TESS (ExoFOP-TESS) website is designed to optimize resources and facilitate collaboration in follow-up studies of targets observed by TESS, an Explorer-class mission led by MIT. ExoFOP-TESS contains stellar parameters from the TESS Input Catalog (TIC), which is served by the Mikulski Archive for Space Telescopes (MAST), and planet parameters from the NASA Exoplanet Archive.

For information about participating in the TESS Guest Investigator program, please see the TESS Science Support Center.

In order to upload your own data, you must have an account. Users are expected to follow the ExoFOP Professional Conduct Policy.

Please include the following standard acknowledgment in any published material that makes use of ExoFOP: "This research has made use of the Exoplanet Follow-up Observation Program website, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program."

ExoFOP Data Migration
The ExoFOP Archive is in the process of migrating to a single portal. The user uploaded content in the Kepler and K2 portals is being incorporated into the TESS portal. The original user and date of the upload will be retained. As content is migrated, the update feature for that parameter class in the original portal will be disabled. See Status.

REQUEST AN ACCOUNT RESET YOUR PASSWORD

TARGETS (TIC V8.1)

TIC ID or Exoplanet Archive name (e.g. 425997655 or K2-96):

Search the TESS Candidate Target List (9,488,282 targets)

Download the TESS Candidate Target List (3.7G)

Follow your favorite targets

TOIS/CTOIS

Includes PlanetHunters

List of all TOIs 2,330

List of all CTOIs 881

NEW Search TOIs

TOI name (e.g. 174 or 174.01):

DATA TAGS

Data Tag (e.g. tag number or yyyymmdd_user_description_nnnn):

View all Data Tags for a user (enter username or leave blank to view your own if you are logged in):

OBSERVATIONS

Imaging 5,166

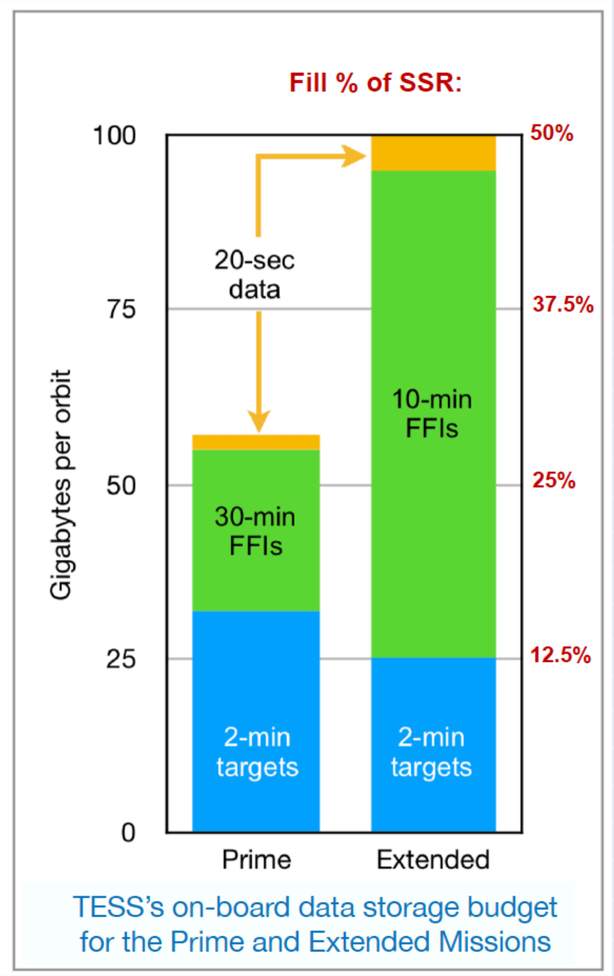
Spectroscopy 4,699

Time Series 4,331

Stellar Companions 3,886

TESS Data Cadences in Extended Mission

- **FFIs have shifted to 10 min cadence**
  - Replaces 30 minute cadence
- **"Postage Stamps" have been augmented**
  - 120s cadence is unchanged
  - 20s cadence has been added
- **Solid State Recorder (SSR) volume usage has increased from ~30% to ~50% in Extended Mission**
  - Margin is needed in case a DSN downlink does not occur for a given TESS orbit, and a make-up DSN pass is needed during the following orbit



TESS's on-board data storage budget for the Prime and Extended Missions

Slide from George Ricker Sci Team Update (MIT)

Comparison: TESS Primary and Extended Missions

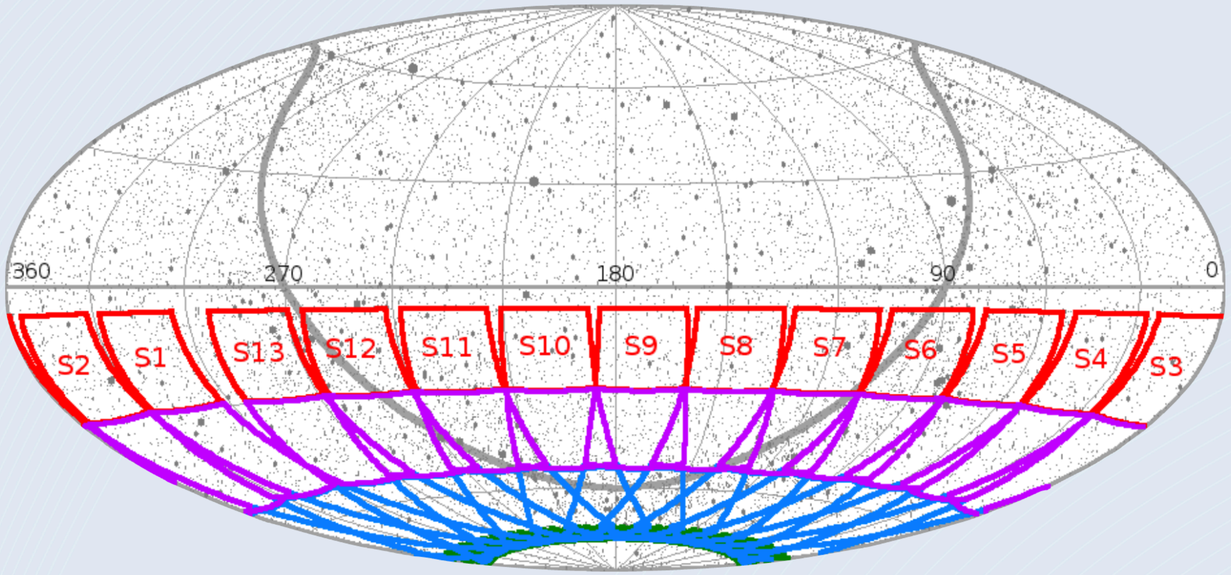
	Prime Mission	Extended Mission	Prime + Extended Missions
Timeframe	Jul 2018 – Jun 2020	Jul 2020 – Sep 2022	**Jul 2018 - Sep 2022**
Total new small planets ($R < 4R_E$)	908	**1331**	**2239**
Planets in or near habitable zone ($0.5 < S/S_E < 2$)	58	**91**	**149**
Planets with periods longer than 20 days	199	**509**	**708**

Simulations from TESS Extended Mission Proposal
(Sullivan+ 2015; Bouma+ 2017; Barclay+ 2018)

Slide from George Ricker Sci Team Update (MIT)

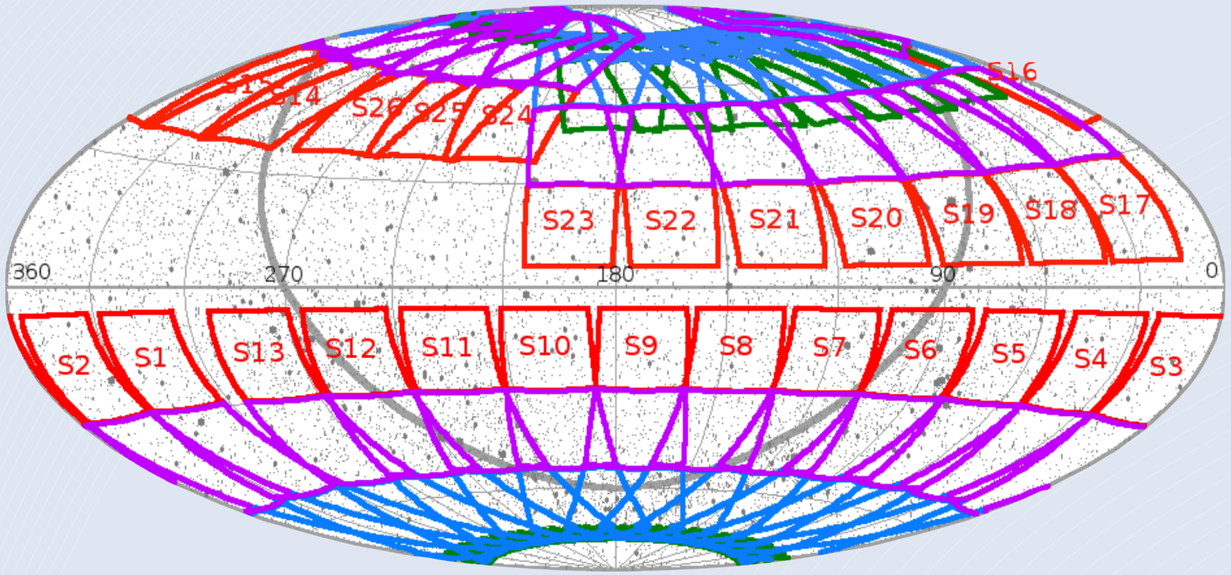
GRR/200825

TESS Sky Coverage Maps



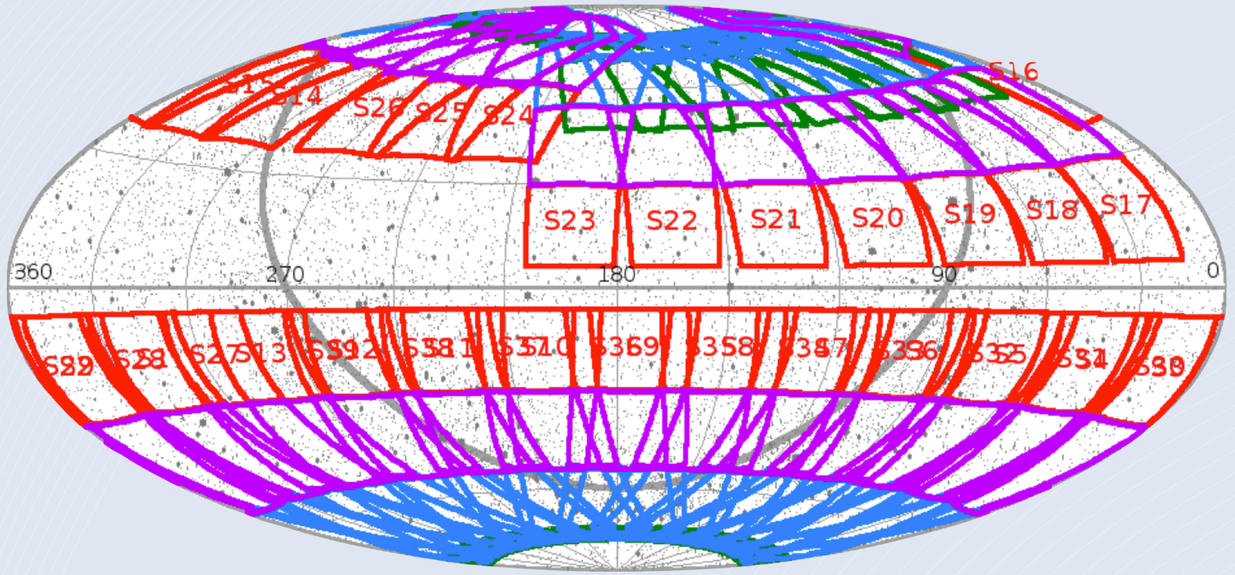
Year 1 of the Mission (Jul 2018-Jun 2019)

TESS Sky Coverage Maps



Adding Year 2 of the Mission (Jul 2019-Jun 2020)

TESS Sky Coverage Maps

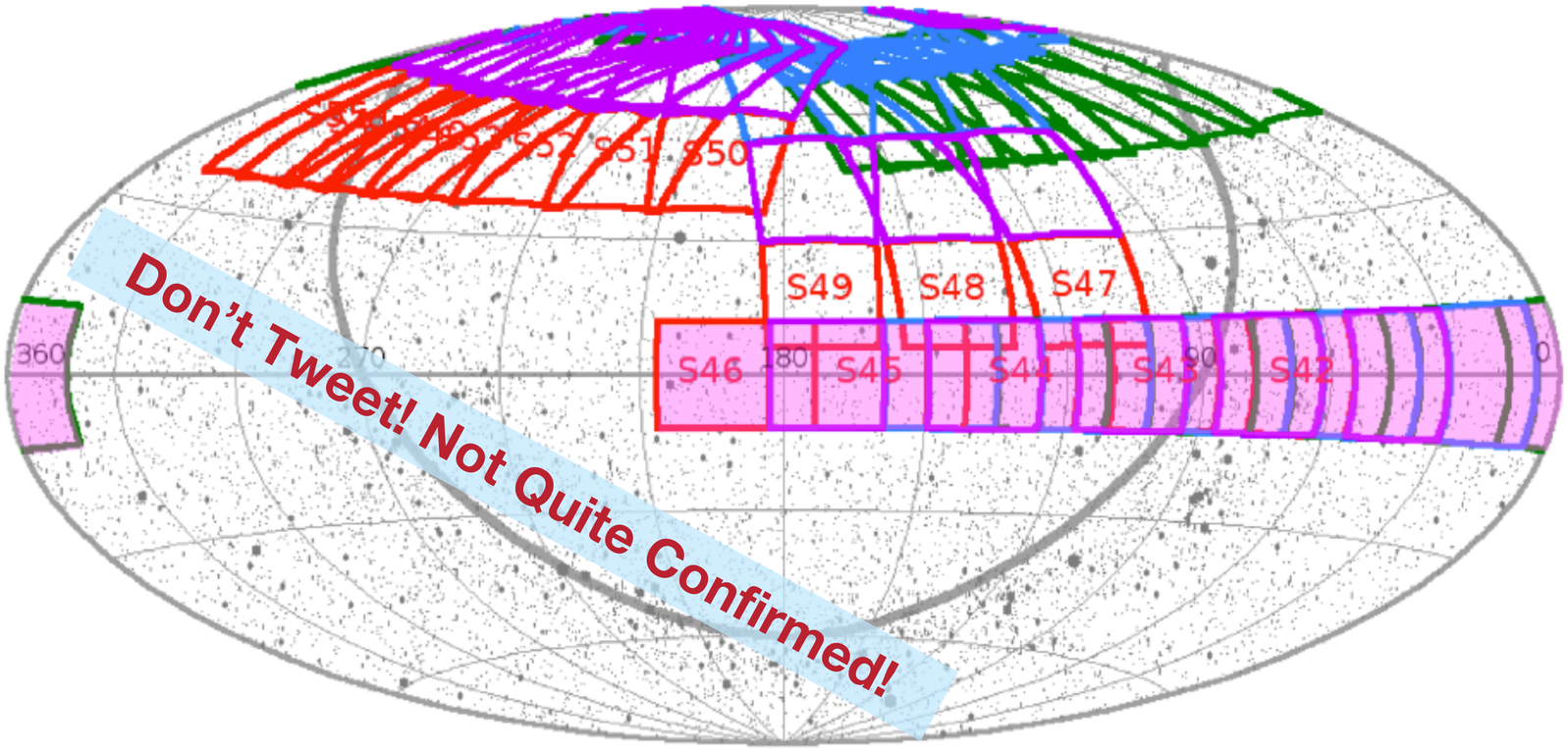


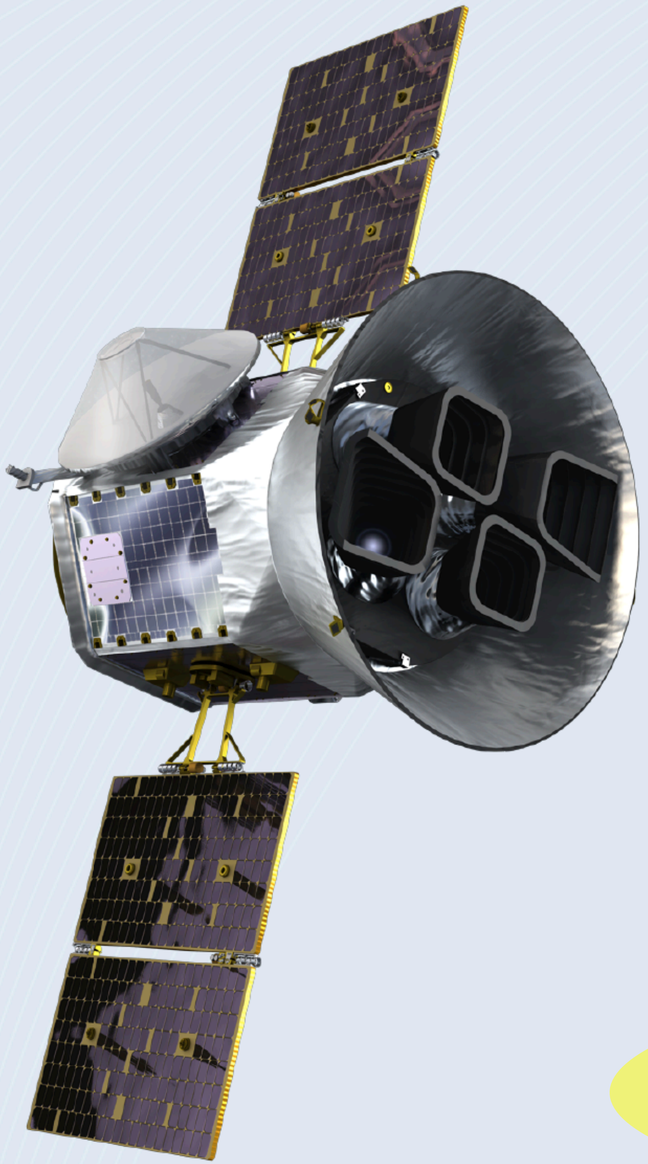
Then Year 3 of the Mission (Jul 2020-Jun 2021)

Plan for Cycle 4 (15 months) nearly finalized

Sector numbers:

40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
N	N	E	E	E	E	E	N	N	N	N	N	N	N	N	N
7/21															9/22





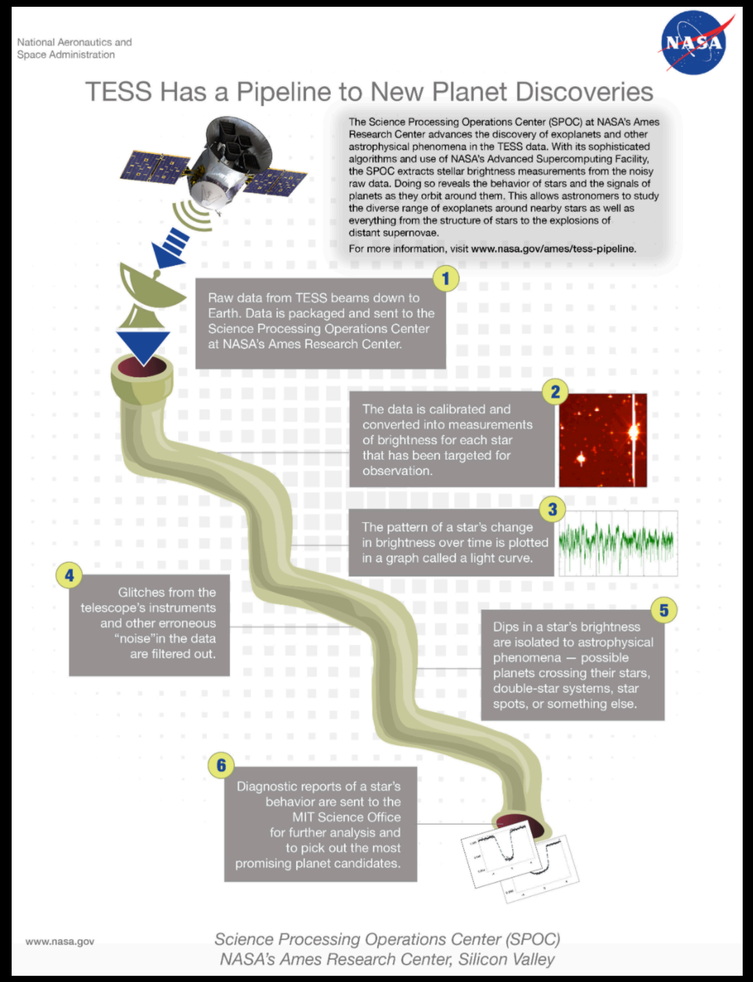
Takeaways: TESS's Current Mission Status

- TESS's unique lunar resonant orbit is greatly simplifying the mission
  - *Stable operations in principle could last until 2038 or later*
- TESS's spacecraft stability is exquisite
  - *20 milli-arcseconds (**1/1000th pixel**) on 1 hour time scales*
- TESS's camera performance is superb
  - *Focus is stable to ~1μm on 1 hour time scales*
  - *Photometric precision is <20 ppm (**3x better than planned**) for bright quiet stars*
  - *Achieving stacked FFI limiting magnitudes fainter than I_{mag}= +21*
- TESS's initial sky survey sector-by-sector was completed successfully
- TESS's extended mission commenced on July 5, 2020
- TESS's full frame images are enabling a wide range of astrophysics discoveries
  - ***Rich trove of high-value exoplanet targets for future missions***
  - ***Transient Science: Stellar Astrophysics, Extragalactic "Multi-Messenger Astronomy", …***
  - ***"Precovery" transient observations are routine***
- **TESS's high science ranking by NASA in mid-2019**
  - ***#1 for Scientific Merit in NASA's 2019 Senior Review of Explorer Missions***
  - ***Invited to the 2022 Astrophysics Senior Review (hopefully, extension to 2025…)***

Slide from George Ricker Sci Team Update (MIT)

Data processing, documentation and archiving

TESS data processed at SPOC/ARC, including multi-sector runs, reviewed with MIT/POC and delivered to MAST @STScI, ahead of schedule



Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

MAST | STScI | Tools | Mission Search | Search Website | Follow Us | Register | Forum

TESS Home | Data Products | Search Tools | Documentation | Tutorials

Notice: Around the end of September 2020, archive.stsci.edu will begin using HTTPS exclusively. *read more*

NOTE: Some Sectors have special memos regarding their processing or delivery. If using those Sectors, be sure to check out the PDF linked in the "Memo" next to the DRN links in the table below.

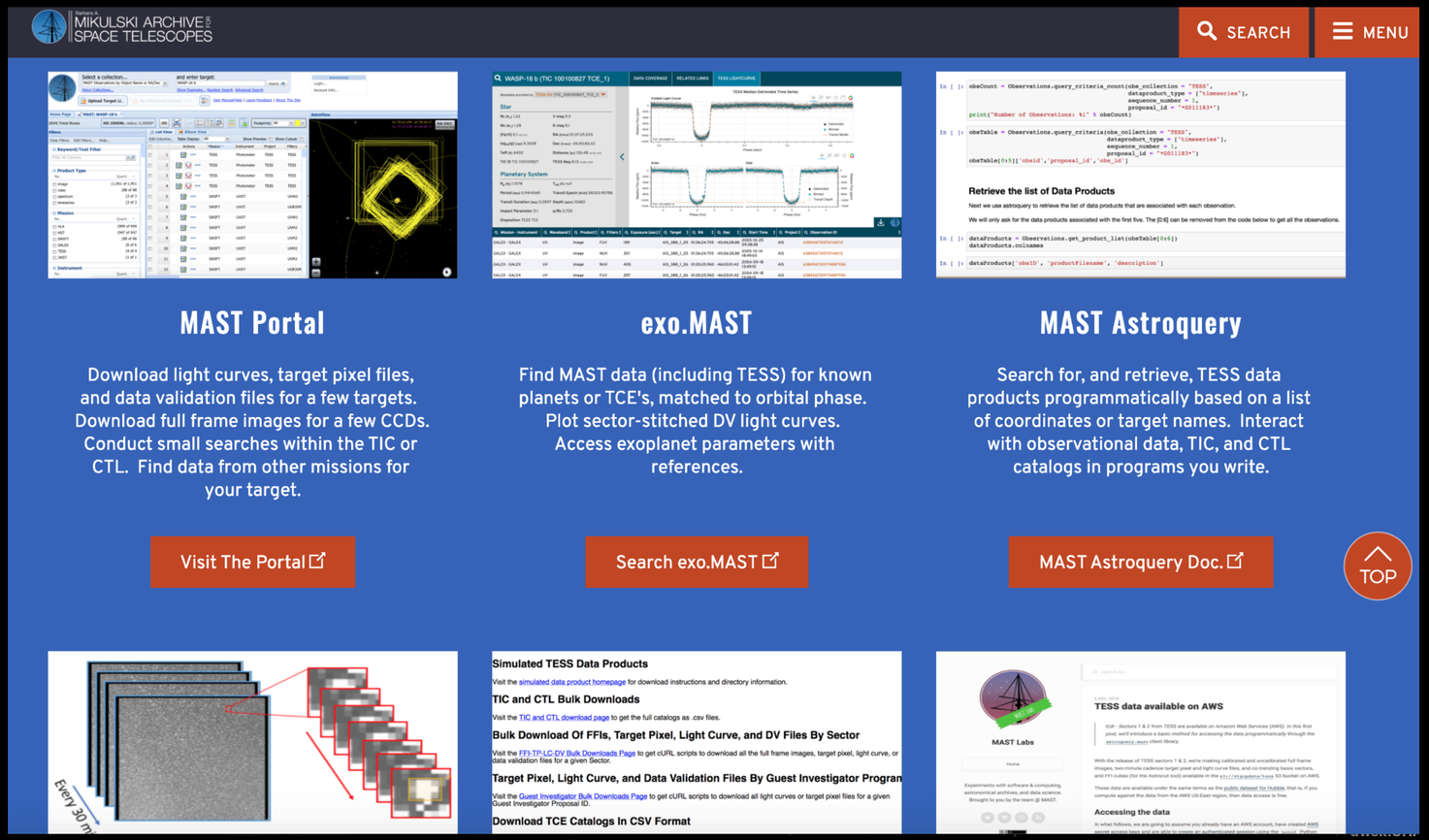
Download all TESS Data Release Notes. The format of the files includes a sector number or range, a data release number ("drn??") that increases with every new Data Release Note and is thus a chronological indicator, and a version number ("v??") in case a given data release note needs to be replaced to fix something.

Note that for multi-sector data release notes, an additional file, called a "target info table", is included in text format. This file contains the set of TESS targets that were searched as part of multi-sector searches, and some additional information on each target's TCE and DV status as part of the run. See the header of the text files for more info.

For your convenience, the start and end times in both UTC and TESS Truncated Julian Date for each orbit in each Sector are provided in this CSV table.

Data Release Notes			
Data Release Number	**Sector(s)**	**PDF File**	**Target Info File (Multisector Only)**
DRN 41	Sector 28	tess_sector_28_drn41_v01.pdf	
DRN 40	Sectors 14-26	tess_multisector_14_26_drn40_v02.pdf	tess_multisector_14_26_drn40_targetinfo_v01.txt
DRN 38	Sector 27	tess_sector_27_drn38_v01.pdf	
DRN 37	Sector 26	tess_sector_26_drn37_v02.pdf	
DRN 36	Sector 25	tess_sector_25_drn36_v02.pdf	

MAST data archive



Extended Mission (Year 3)

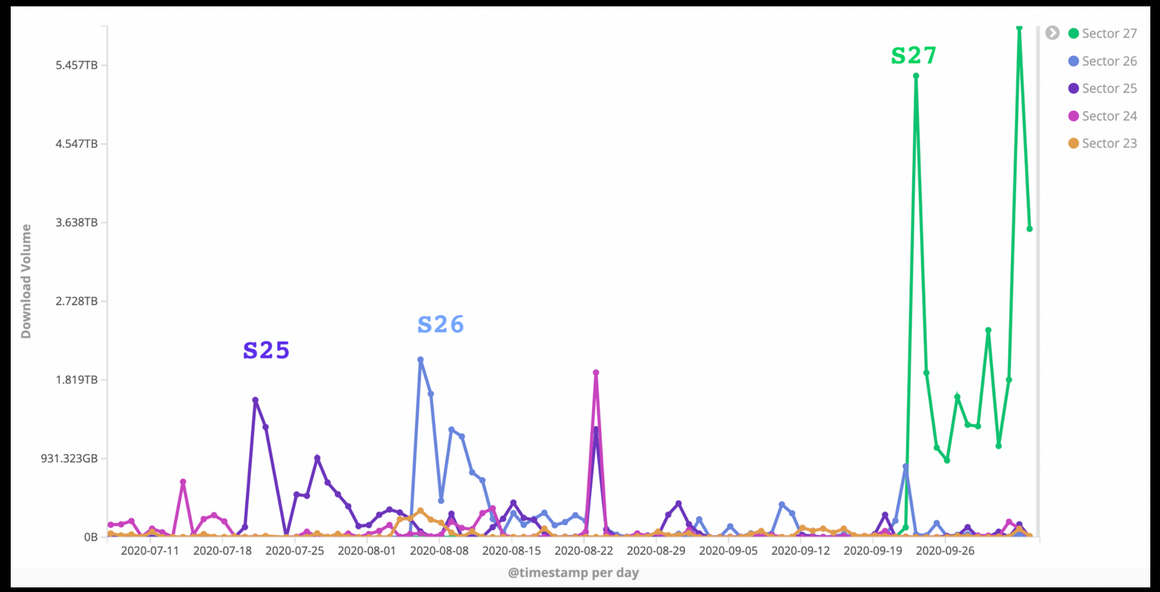
Service/Sector	S27	S28	S29	S30	S31	S32	S33	S34
Data Ingest Started	☑	☑	☐	☐	☐	☐	☐	☐
Portal/Astroquery	☑ FFI ☑ TP/LC/DV	☑ FFI ☑ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV
Bulk Downloads	☑ FFI ☑ TP/LC/DV	☑ FFI ☑ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV
TESSCut	☑	☑	☐	☐	☐	☐	☐	☐
TCEs available in exo.mast	☑	☑	☐	☐	☐	☐	☐	☐
Data Release Notes	☑	☑	☐	☐	☐	☐	☐	☐
Data available on Amazon Cloud	☑ FFI ☑ TP/LC/DV	☑ FFI ☑ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV	☐ FFI ☐ TP/LC/DV

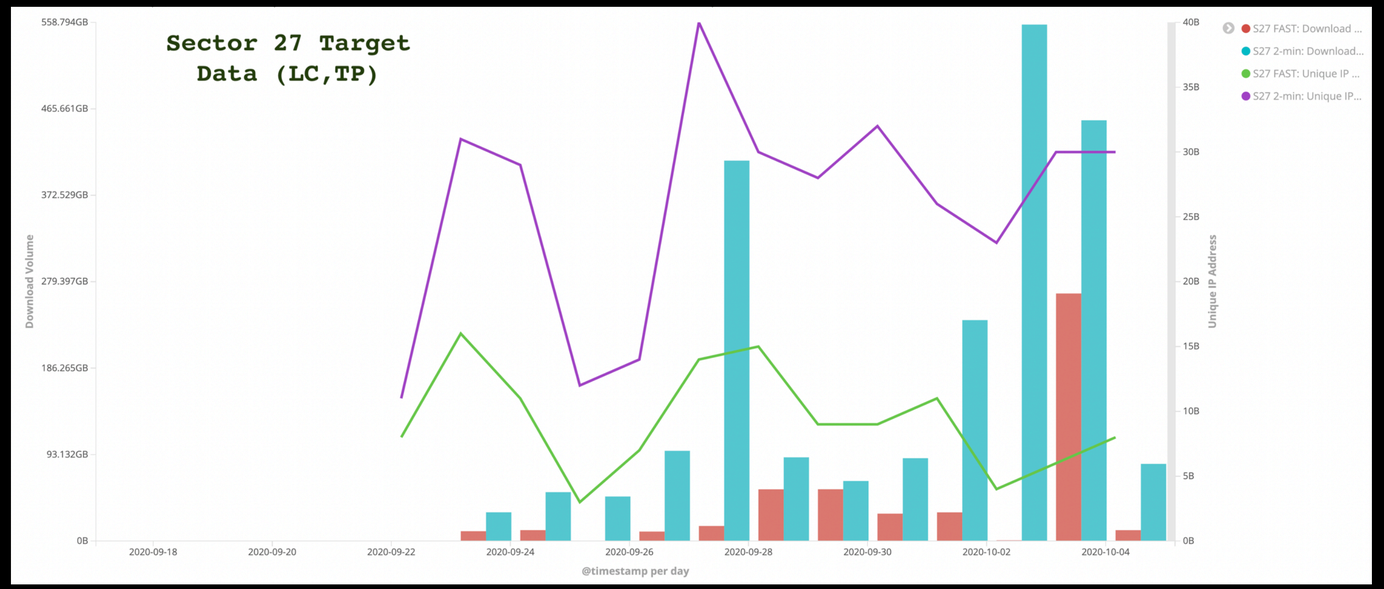
Prime Mission (Year 2, Northern Hemisphere)

DR30 refers to the reprocessed data which will replace the original data in the MAST archive.

Service/Sector	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25
Data Ingest Started	☑ orig ☑ DR30	☑ orig ☑ DR30	☑ orig ☑ DR30	☑ orig ☑ DR30	☑ orig ☑ DR30	☑ orig ☑ DR30	☑	☑	☑	☑	☑	☑
Portal/Astroquery	☑ orig	☑ orig	☑ orig	☑ orig	☑ orig	☑ orig	☑	☑	☑	☑	☑	☑

MAST data archive





Data download volume and unique PI addresses imply many groups accessing the 10-min FFIs, 2-min and 20-s light curves as soon as available.

Plots from S. Mullally (STScI/MAST)

MAST Hosts TESS High Level Science Products
Example- CDIPS. Others available. More coming soon!

CDIPS: DR4 (Bouma et al.)

http://archive.stsci.edu/hlsp/cdips

Cluster Difference Imaging Photometric Survey

- Light curves from FFIs of targets that are candidate members of open clusters, moving groups, or otherwise show evidence of youth.
- Latest release, DR4, contains 26,956 light curves from Sectors 1-5. This release also completes the Southern Hemisphere with CDIPS light curves now available for Sectors 1-13.
- Also included for the first time: a catalog of target metadata, including Gaia parallax and magnitude values, along with cluster membership provenances.
- DR4 is public online now, bulk scripts work, Portal and astroquery updates will be done soon. Look for announcement on MAST social.

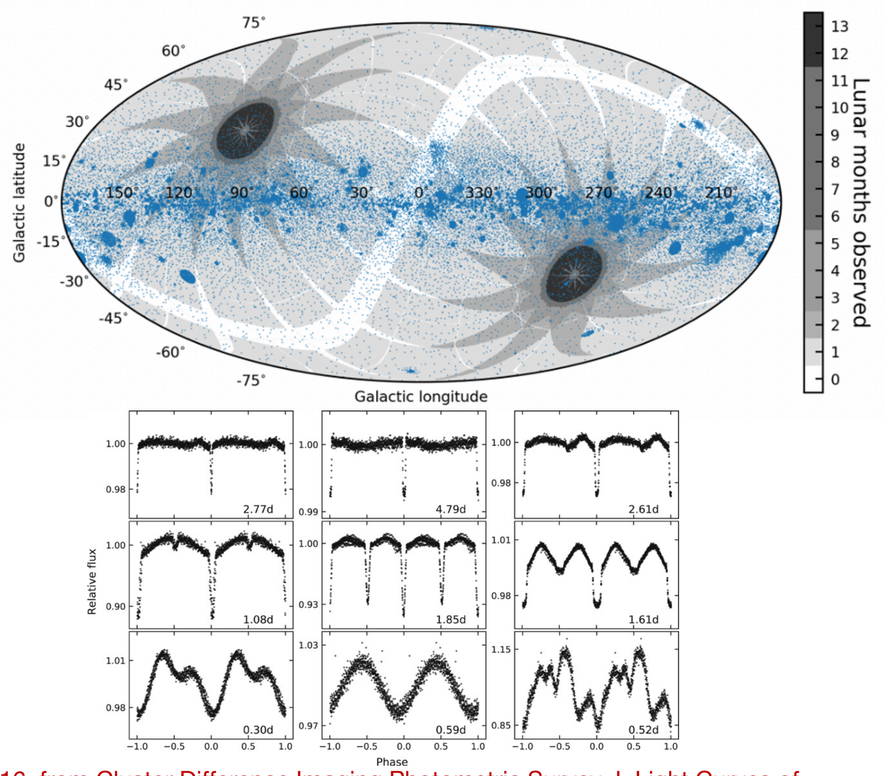
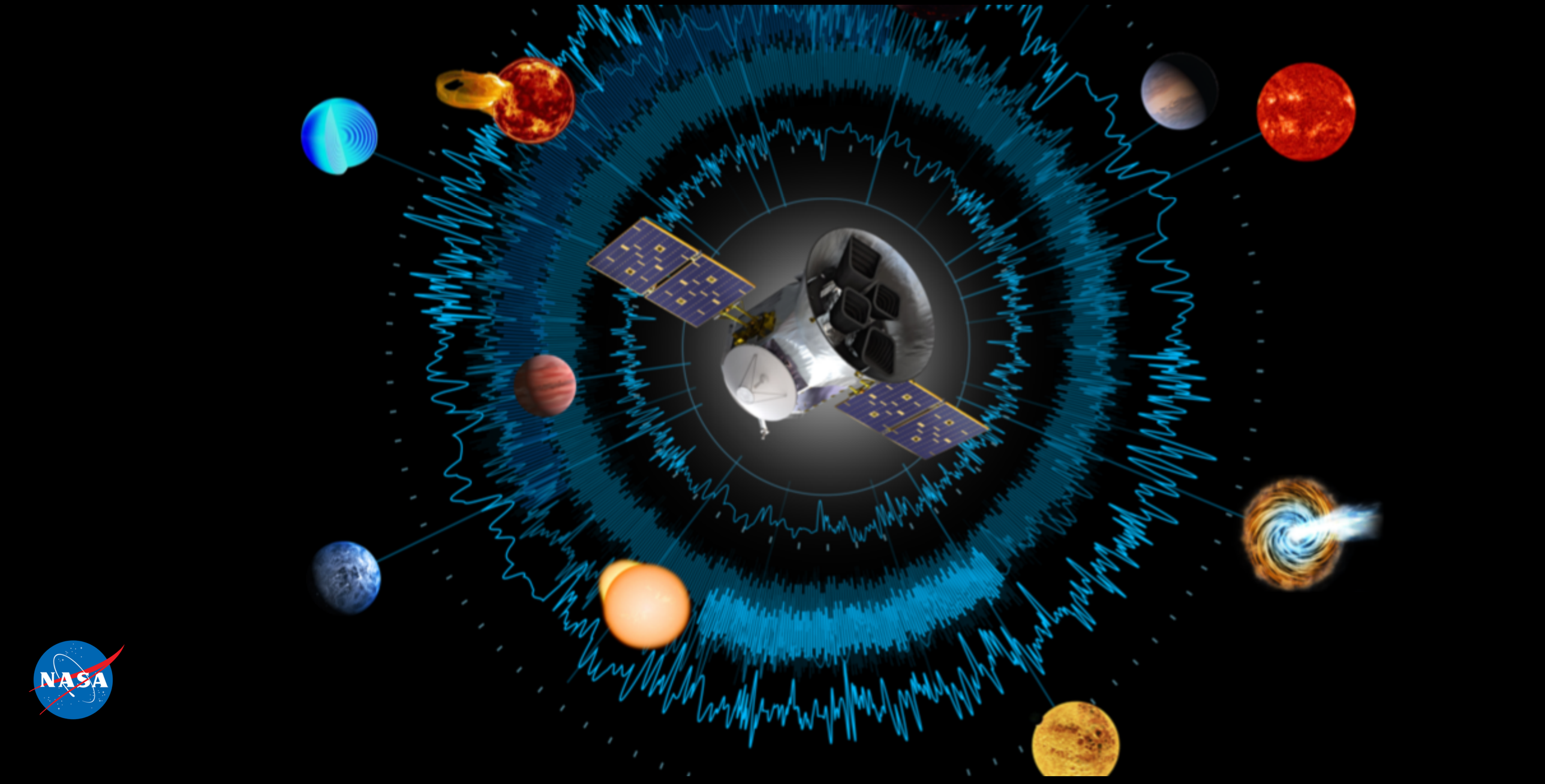


Figure 16. from Cluster Difference Imaging Photometric Survey. I. Light Curves of Stars in Open Clusters from TESS Sectors 6 and 7
2019 APJS 245 13 doi:10.3847/1538-4365/ab4a7e
http://dx.doi.org/10.3847/1538-4365/ab4a7e

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

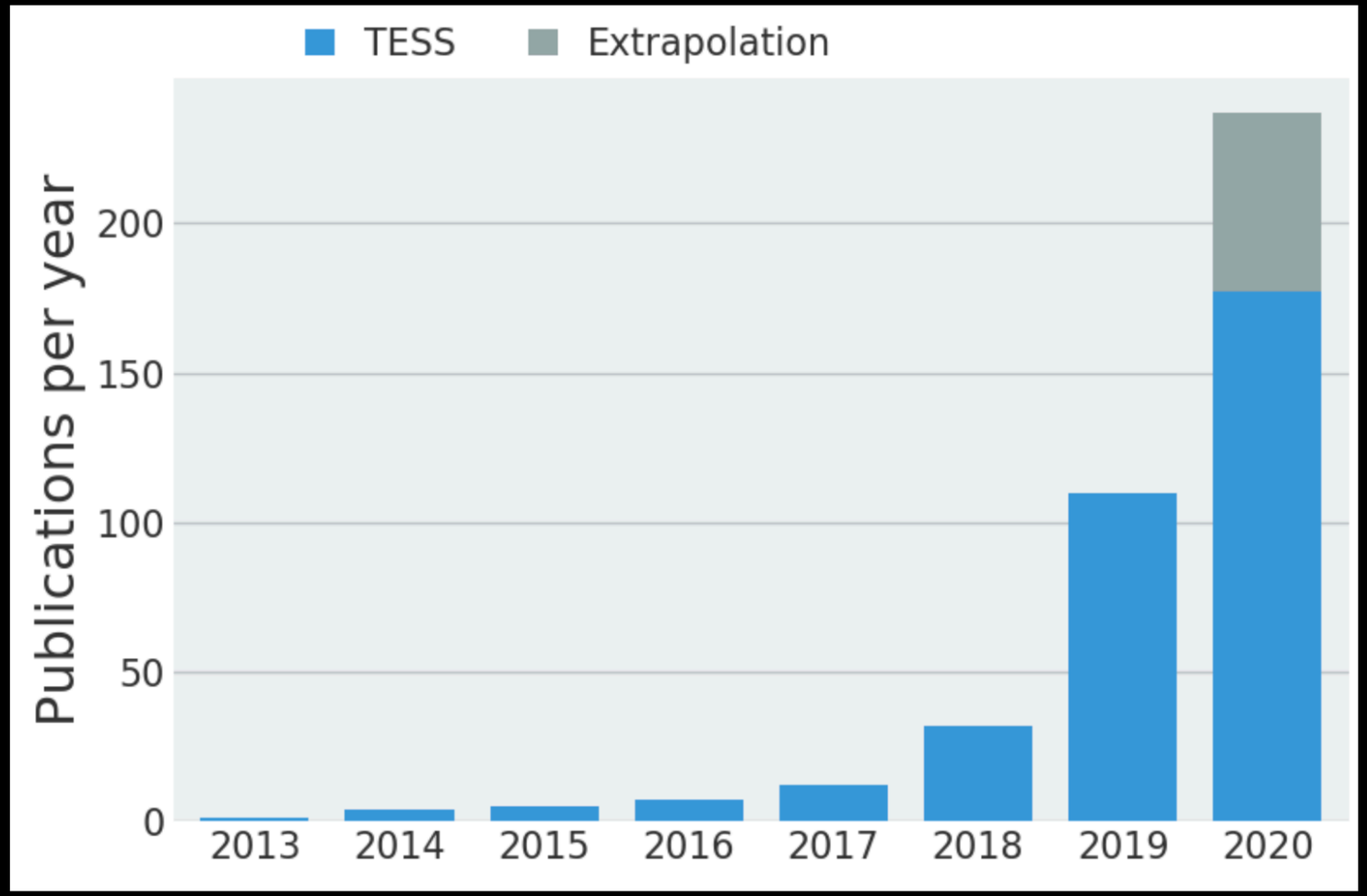
Slide from S. Fleming (STScI/MAST)

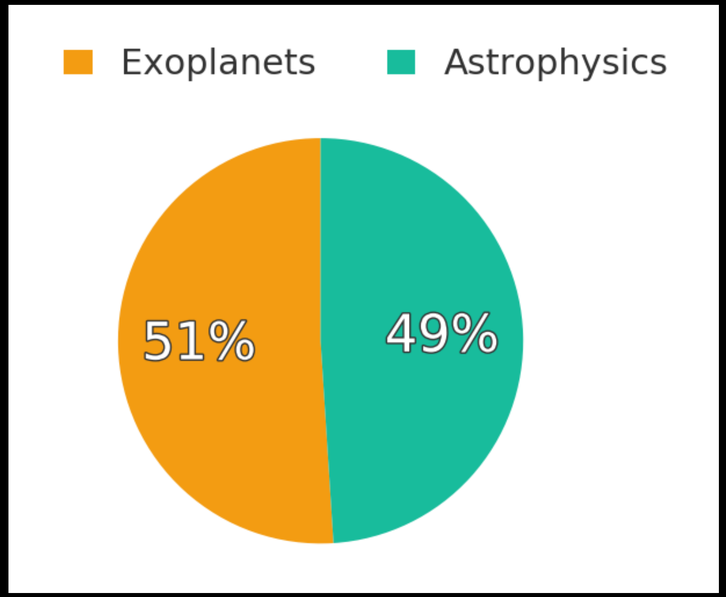
TESS GI Program



TESS Publications Update (October 2020)

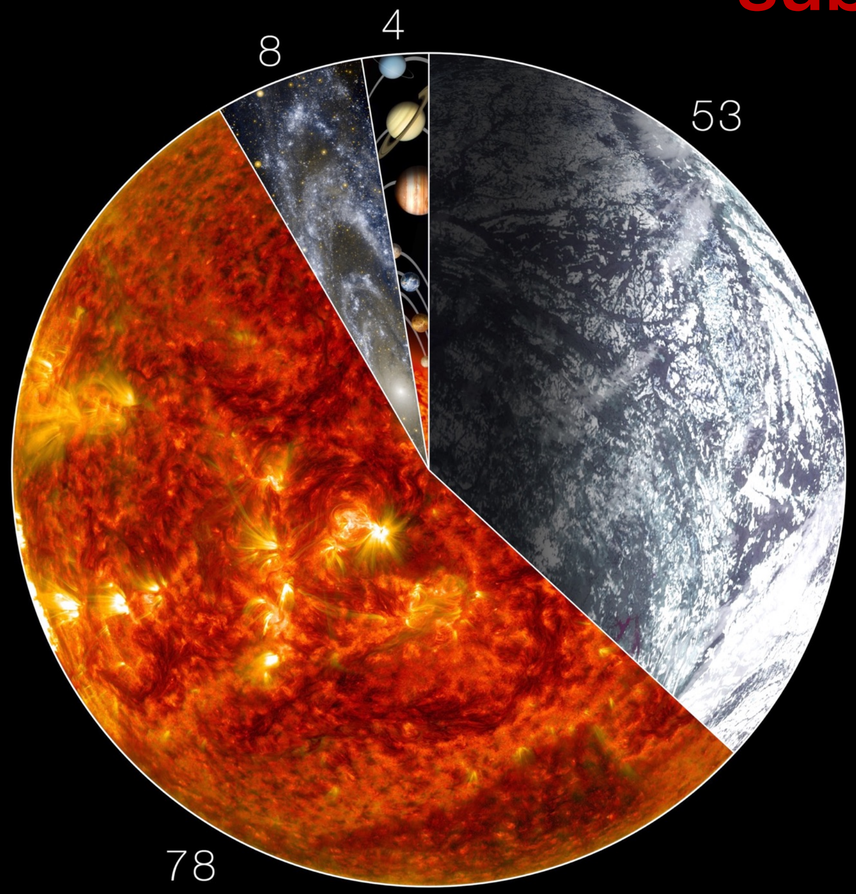
We track TESS publications
348 publications, of which 285 are peer-reviewed



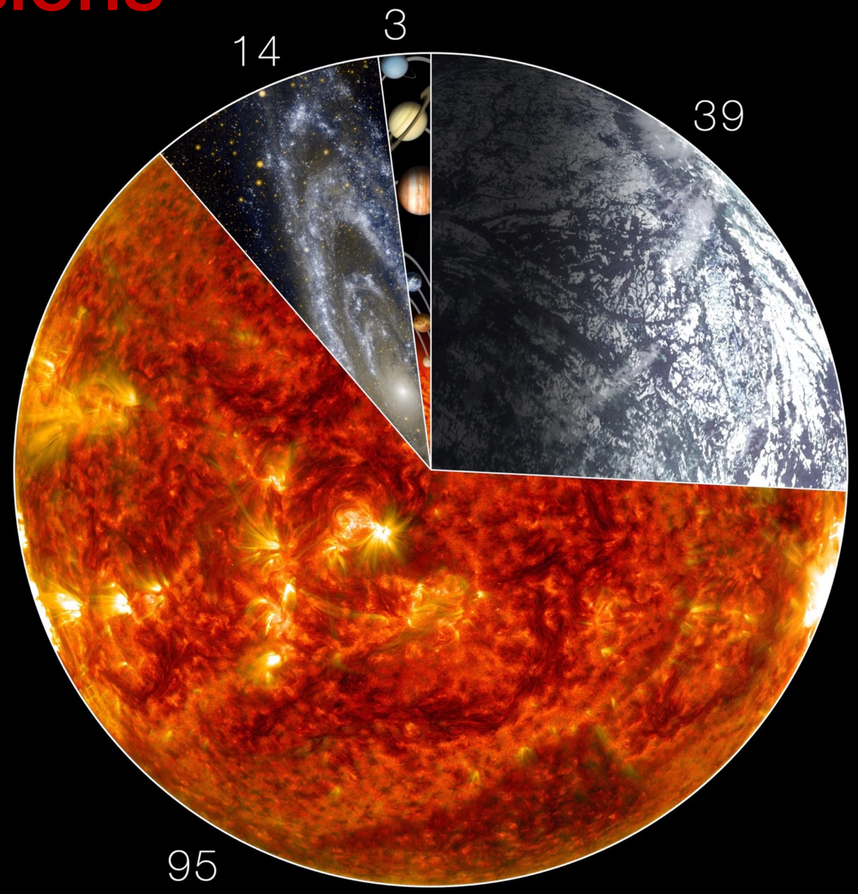


Slide from K. Colón (NASA Goddard)

GI Program-Prime Mission submissions



Cycle 1

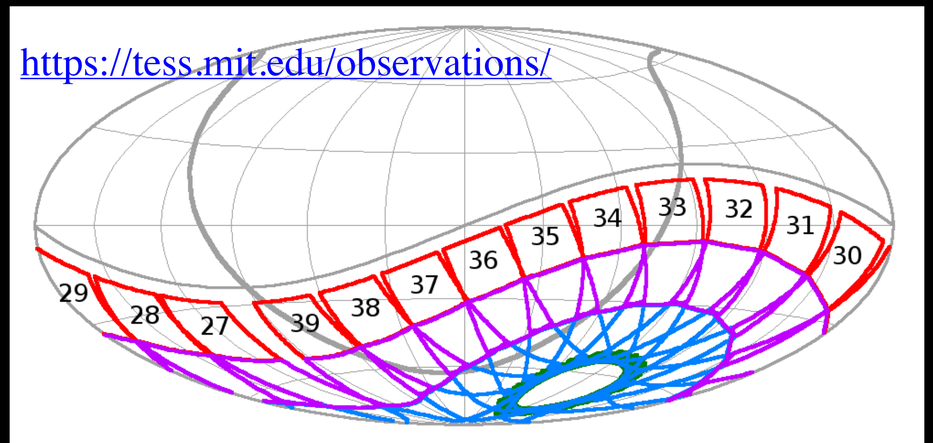


Cycle 2

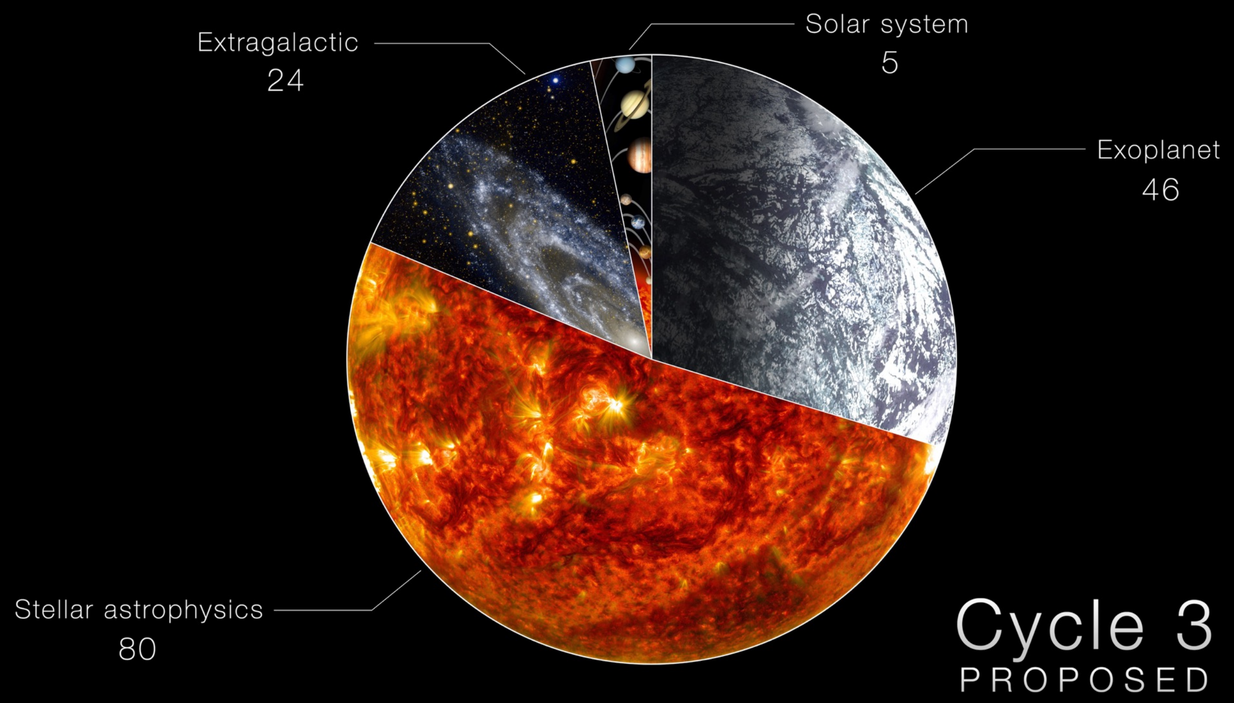
TESS Cycle 3 GI Program

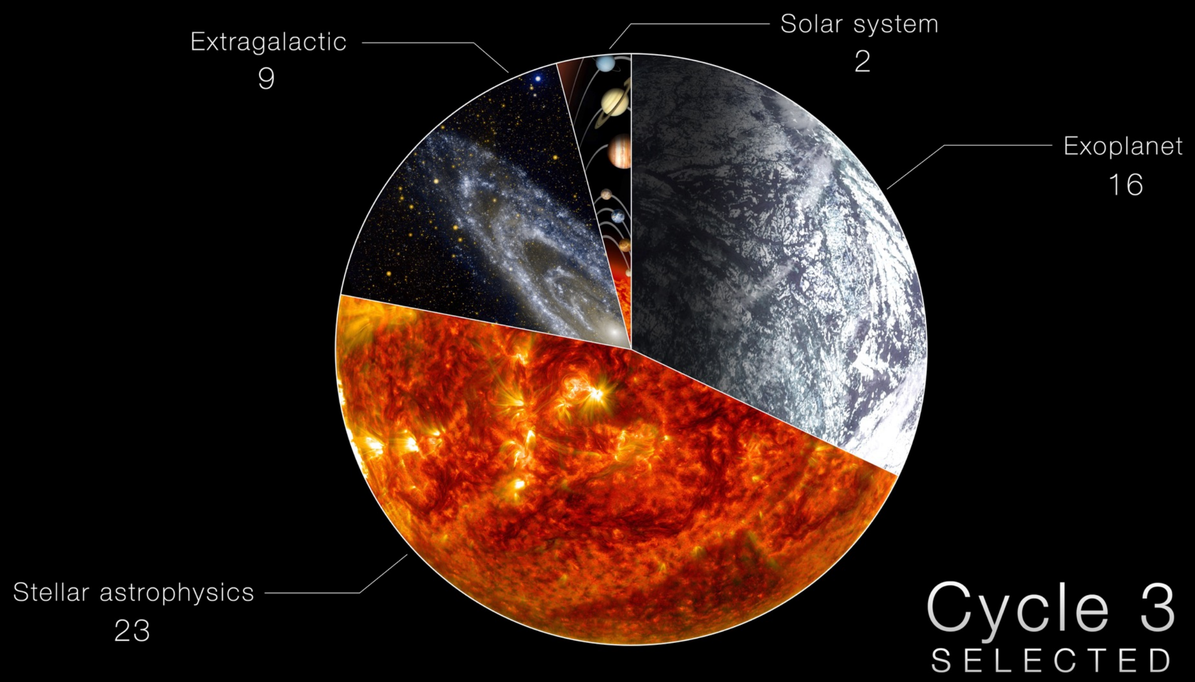
- Cycle 3 spans the first year of the Extended Mission (Sectors 27-39 i.e. July 4, 2020 - June 24, 2021)
- Pointings cover the Southern Ecliptic hemisphere
- New 20-second cadence mode with ~600 target slots available to the community per sector
- An 8x increase in the number of 2-minute cadence targets available to the GI program with >12,000 target slots per sector
- FFI cadence reduced from 30 minutes to 10 minutes

The TESS Cycle 3 peer review transitioned from in-person to a fully virtual review with just weeks to replan, and we are indebted to the NASA and NRESS support staff as well as all of our reviewers across multiple time zones and locations for their flexibility and resiliency for making this a smooth transition.



GI Program-Extended Mission





TESS Cycle 3 GI Program

- >$3M awarded in total to US investigators for science programs that will analyze 10-minute (FFI), 2-minute, or 20-second cadence data or for ground-based observing programs that will support the interpretation of TESS data. PSD funded a highly-ranked solar system key project.
- Selected programs include:
  - Large and Small programs for analysis of FFI, 2-minute, and/or 20-second cadence data
  - Key Projects (which have a maximum duration of 27 months)
  - Ground-based observing programs
  - Joint TESS-Swift programs
  - Joint HST-TESS program (through HST Cycle 28)

https://heasarc.gsfc.nasa.gov/docs/tess/approved-programs.html

Slide from K. Colón (NASA Goddard)

Lightkurve

Adding more TESS tutorials and working to make sure lightkurve is compatible with 20-second cadence data

A friendly package for Kepler & TESS time series analysis in Python.

Quickstart →

Time domain astronomy made easy for all

Lightkurve offers a user-friendly way to analyze time series data obtained by telescopes, in particular NASA's Kepler and TESS exoplanet missions.

Lightkurve aims to lower barriers, promote best practices, reduce costs, and improve scientific fidelity by providing accessible Python tools and tutorials.

```
import lightkurve as lk

pixels = lk.search_targetpixelfile("Kepler-10").download()
pixels.plot()

lightcurve = pixels.to_lightcurve()
lightcurve.plot()

exoplanet = lightcurve.flatten().fold(period=0.838)
exoplanet.plot()
```

Slide from K. Colón (NASA Goddard)

https://docs.lightkurve.org/

TESS Cycle 4 GI Program

- Proposal deadline anticipated to be the week after AAS in January 2021 with the call coming out in late October 2020
- Cycle 4 observations expected to start in June 2021 and to span 16 sectors
- Pointings will cover the Northern Ecliptic hemisphere and part of the Ecliptic plane (including revisits of K2 Campaign FOVs)
- Proposals for 2-minute and 20-second cadence targets and for funding to support the analysis of new 2-minute, 20-second, and FFI data will be solicited
- Ground-based focused programs that support the analysis of TESS data will be solicited
- Joint programs with Swift will be solicited (for up to 100 ks of Swift time)
- Joint programs with HST will be solicited (through the HST Cycle 29 call)
- Joint programs with Fermi will be solicited (through the Fermi Cycle 14 call)

Slide from K. Colón (NASA Goddard)

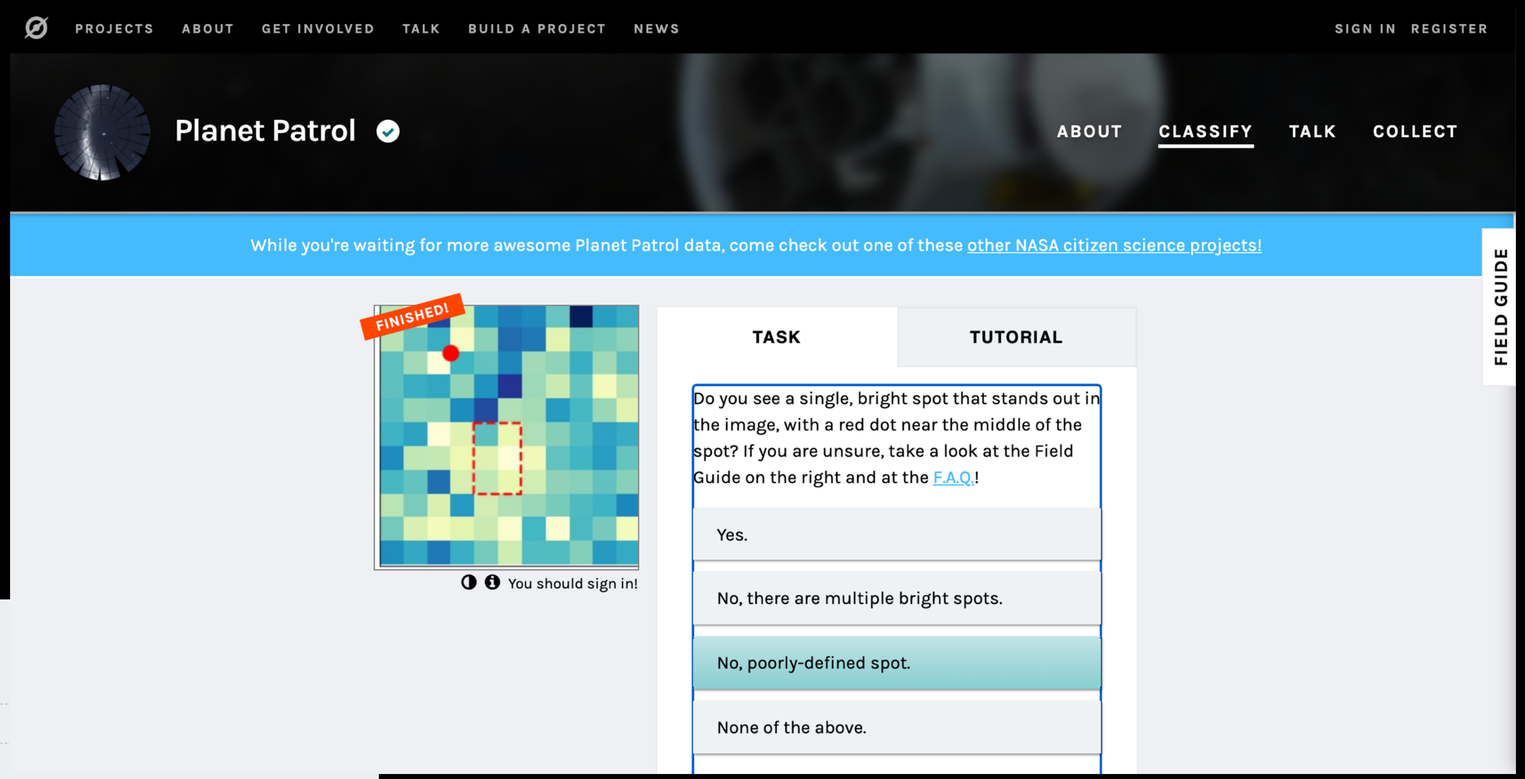
Changes from Cycle 3

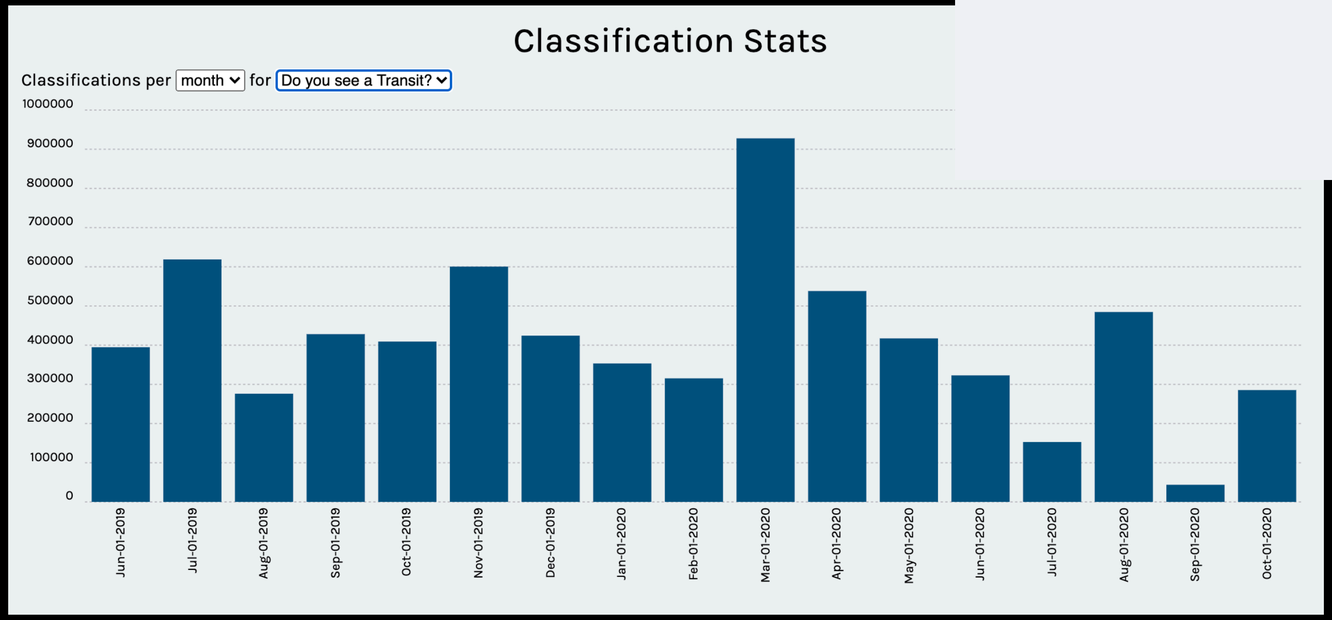
- Proposals will be dual-anonymous
- Total funding awarded will be increased compared to previous cycles since Cycle 4 (16 sectors) is longer than previous cycles (13 sectors each)
- Soliciting short ”mini” proposals for small numbers of targets (and no funding)
- Joint programs with Fermi are expected to be solicited (through the Fermi call)
- Key Project proposals will not be solicited (since Cycle 4 is end of EM1)

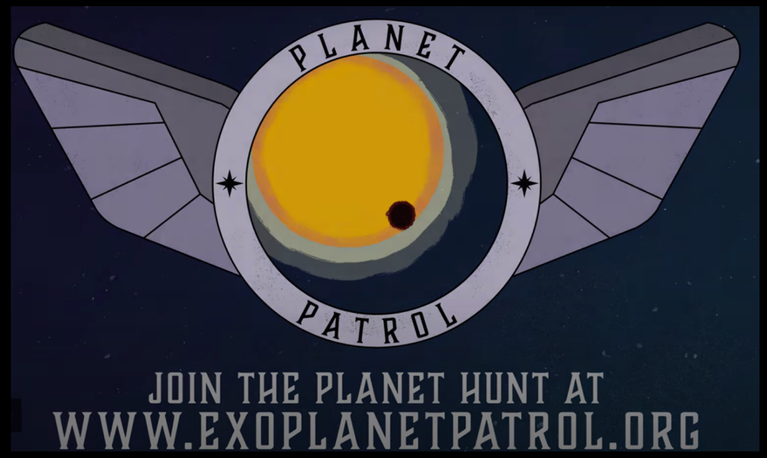
Slide from K. Colón (NASA Goddard)

TESS Citizen Science

Planet Hunters TESS

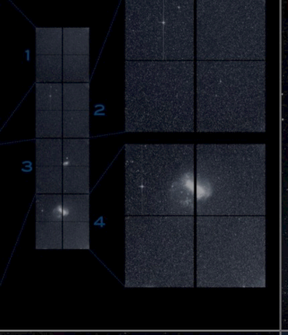






Summary

- TESS Prime Mission completed in July with all systems operating well, meeting or exceeding requirements
- All science data collected; all science data processed and delivered to MAST archive with no proprietary period, ahead of schedule
- TESS data holdings at MAST remain popular with the science community
- GI Program continues to be very popular in areas from solar system to extragalactic objects
- Extended Mission now well underway. New data modes working well
- TESS key science results receive high visibility in online news sites and social media
- Citizen science projects well underway and engaging broad community
- All spacecraft and ground systems remain healthy, and we look forward to many more years of exciting science enabled by TESS.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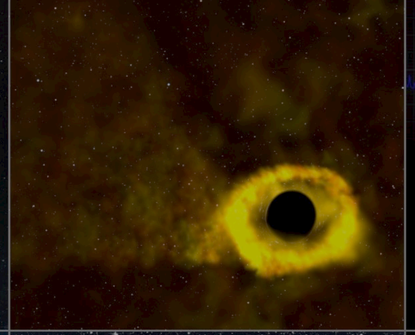
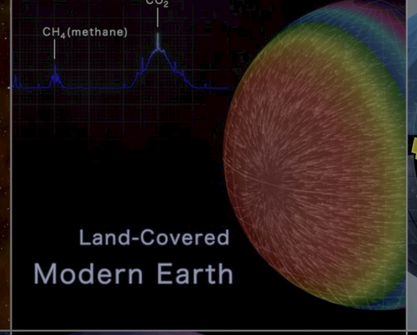
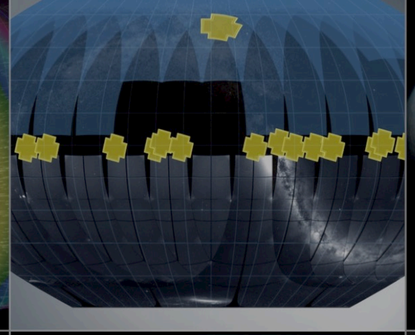
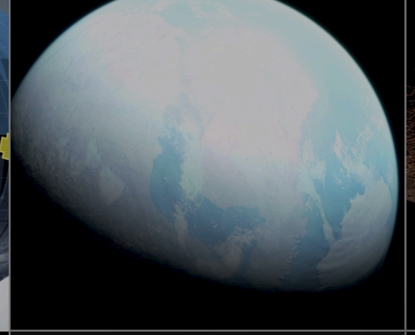
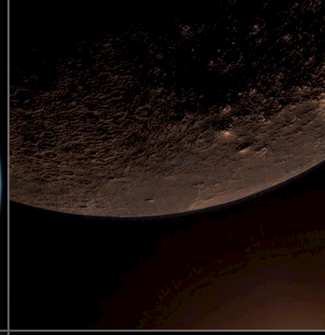
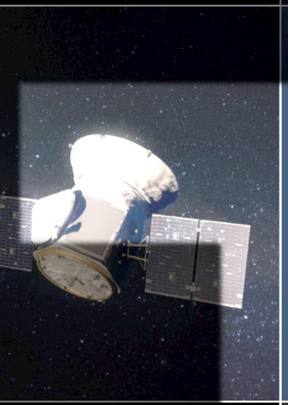
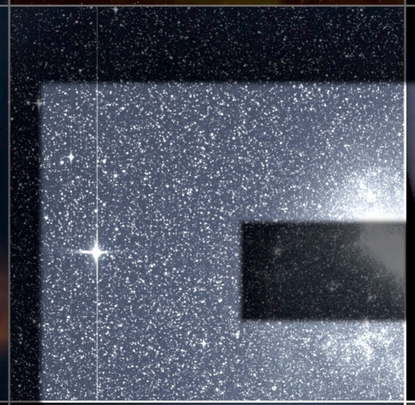
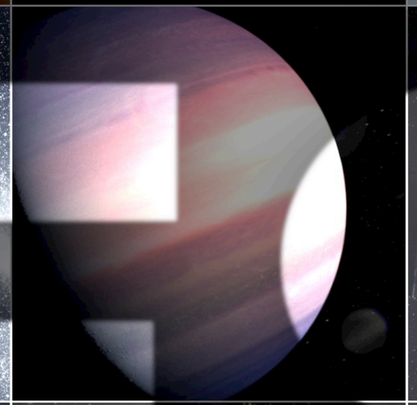
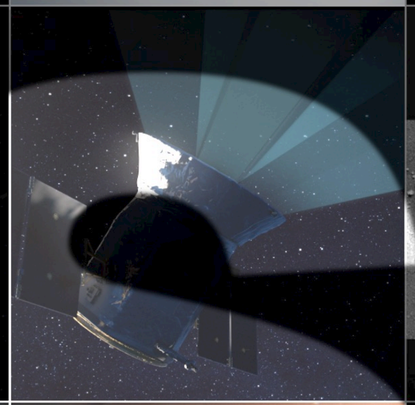
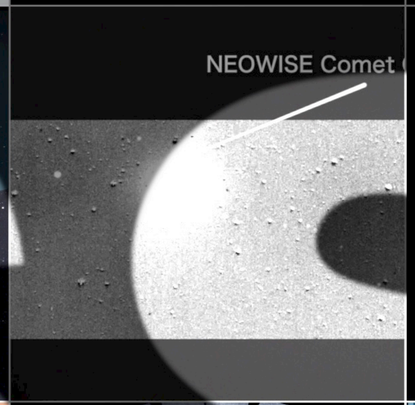
2
3
4



CH_4(methane)
CO_2
Land-Covered
Modern Earth



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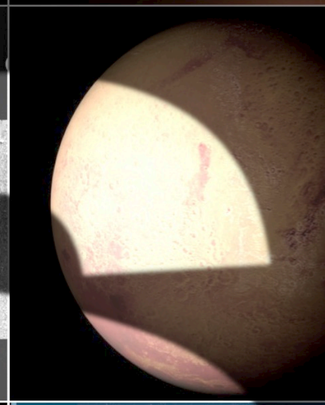
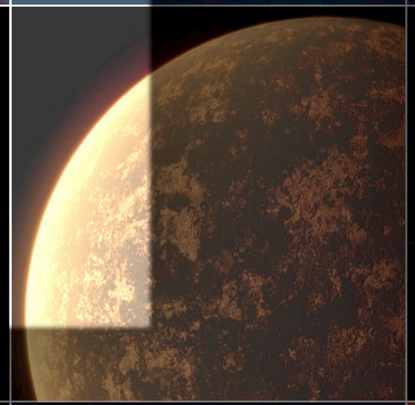
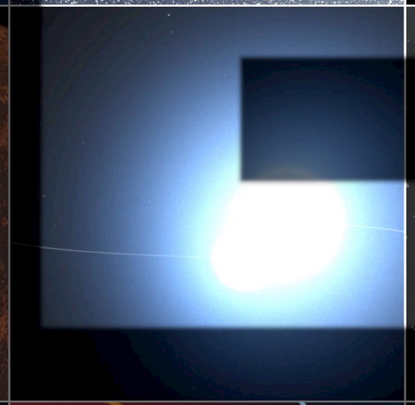
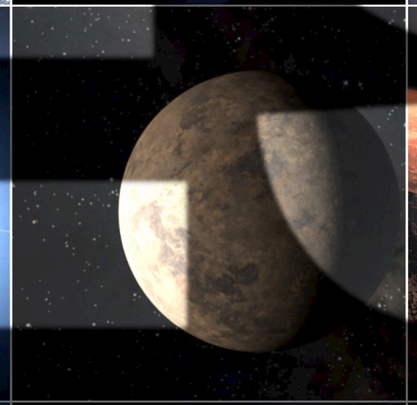
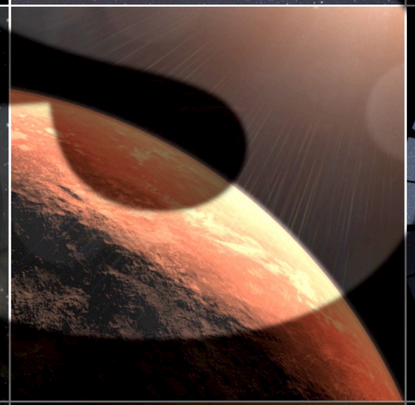
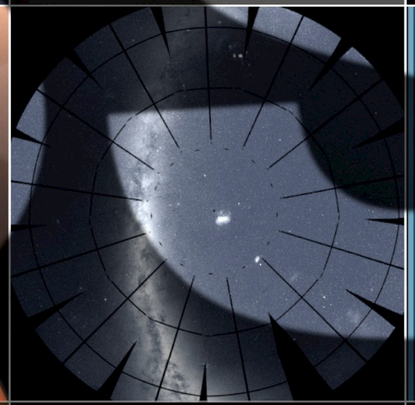
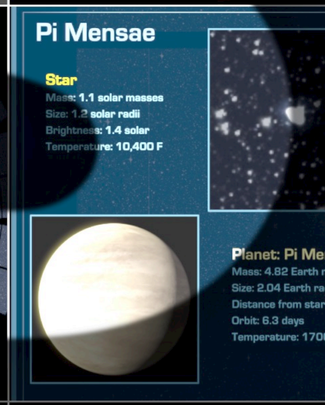
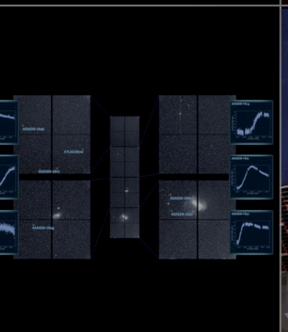
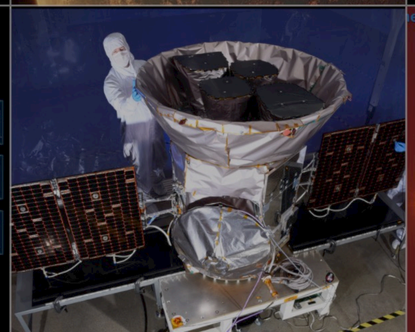
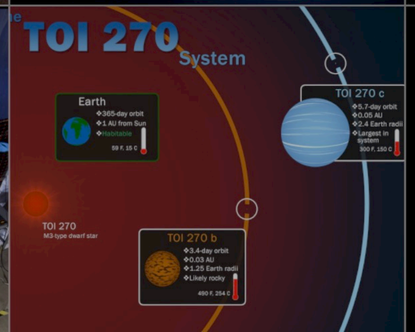


L 98-59b
Earth
L 98-59d






Pi Mensae
Star
Mass: 1.1 solar masses
Size: 1.2 solar radii
Brightness: 1.4 solar
Temperature: 10,400 F
Planet: Pi Me
Mass: 4.82 Earth
Size: 2.04 Earth ra
Distance from star
Orbit: 6.3 days
Temperature: 170



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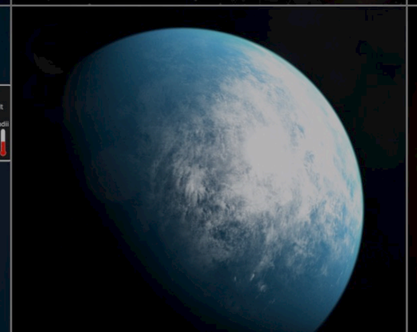
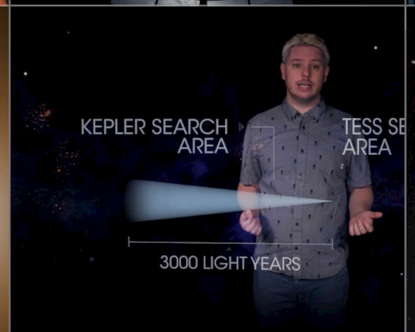
Earth
365-day orbit
1 AU from Sun
Habitable
59 F, 15 C
TOI 270 c
5.7-day orbit
0.05 AU
2.4 Earth radii
Largest in system
300 F, 150 C
TOI 270
M3-type dwarf star
TOI 270 b
3.4-day orbit
0.03 AU
1.25 Earth radii
Likely rocky
480 F, 254 C



KEPLER SEARCH AREA
TESS SE AREA
3000 LIGHT YEARS